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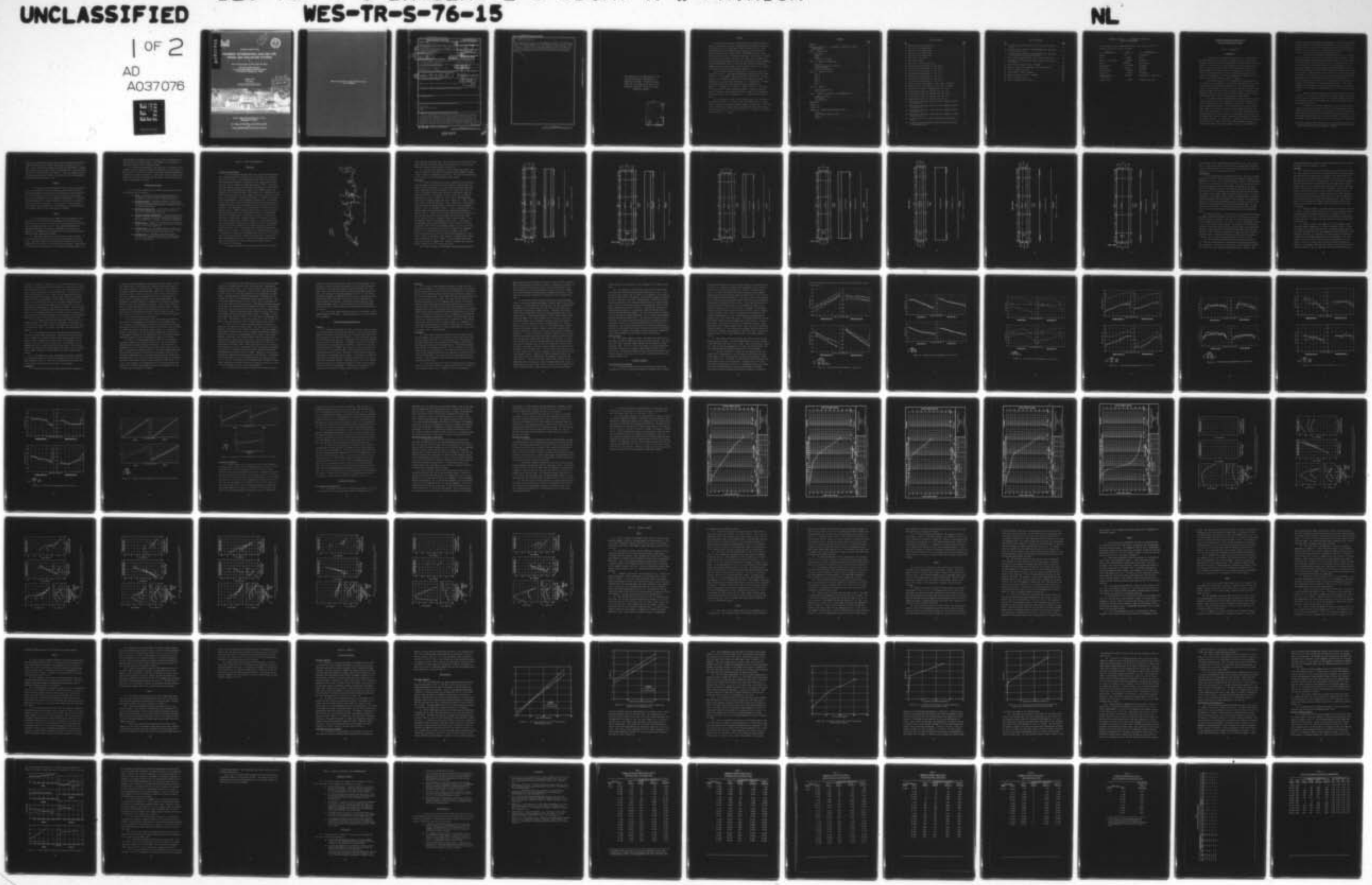

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PAVEMENT DETERIORATION ANALYSIS FOR DESIGN AND EVALUATION SYSTEMS

by

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This investigation was conducted to collect pertinent data from the field that, upon analysis, would provide for initial and partial development of deterioration relationships on roads subjected to vehicle traffic. The field tests were conducted in the Stanislaus National Forest near Sonora, California, on a road network that experienced extensive log-hauling traffic during the testing period. The testing included measuring the traffic volume and traffic weights, measuring the condition of the road surface, and
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conducting various soil tests on the pavement and subgrade. This report contains a detailed discussion of the test procedures, results, and data analysis as well as a general summary of the road construction and maintenance in the testing area. Results of the field tests showed that definitive deterioration relationships could not be developed from the data collected but that a sustained test program could provide for the deterioration relationships desired.

PREFACE

The studies and analyses reported herein were conducted under the auspices of Research for Lines of Communication Facilities in Theaters of Operations, Project 4A162121AT31, Task 01, Work Unit 001, "Road Capability-Analysis and Modification," and Engineering Criteria for Design and Construction (O&MA), Project 4K078012AQ61, Task 02, Work Unit 001, "Deterioration of Pavement Surfacings." This effort is chiefly a continuation of research initiated in FY 1972 under the auspices of Military Engineering Design and Expedient Construction Criteria (MEDECC), Project 4A062112A859, Task 01, Work Unit 002, "Theater of Operations Highway and Storage Area Design" and continued as Work Unit 15, "Theater of Operations Road Networks Throughput Capability."

This investigation was accomplished as a cooperative effort by elements of the U. S. Army Engineer Waterways Experiment Station (WES) and the U. S. Department of Agriculture Forest Service (FS). Persons involved in planning and conducting the field tests were Messrs. V. M. Dekalb and D. L. Jones of the FS, Messrs. N. R. Murphy and P. E. Speake of the WES Mobility and Environmental Systems Laboratory, and Messrs. V. C. Barber, E. C. Odom, R. W. Patrick, and R. T. Sullivan of the WES Soils and Pavements Laboratory (S&PL). Analysis of data and report preparation were conducted by Messrs. Barber, Odom, and Patrick. Structural analysis was performed by Dr. G. M. Hammitt II of the WES S&PL.

The investigation, analysis, and reporting were under the general supervision of Messrs. J. P. Sale, Chief of the S&PL, and D. M. Ladd, Chief, Design Criteria Branch, Pavement Design Division, S&PL. Directors of WES during the planning, testing, analysis, reporting, and publication phases were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
acres	4046.856	square metres
pounds (mass)	0.4535924	kilograms
kips (mass)	453.5924	kilograms
pounds (force)	4.448222	newtons
kips (force)	4.448222	kilonewtons
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
miles per hour	1.609344	kilometres per hour

PAVEMENT DETERIORATION ANALYSIS FOR DESIGN AND EVALUATION SYSTEMS

PART I: INTRODUCTION

Background

1. Research and development efforts at the U. S. Army Engineer Waterways Experiment Station (WES) from 1970 to 1974, in the areas of both ground mobility and soils and pavements, have resulted in the development of a system for use in the analysis of vehicle and road interaction. This Vehicle/Road Compatibility Analysis and Modification System (VRCAMS) uses state-of-the-art design as well as evaluation criteria and methodology in the areas of mobility, geometrics, structures, and maintenance to determine and measure the compatibility of a vehicle with the environment on which it operates.

2. The VRCAMS consists of five computational modules which are (a) mobility and ride dynamics, (b) traffic volume/capacity, (c) structural analysis, (d) maintenance analysis, and (e) vehicle movement modules. The synergetic combination of these modules provides for computerized computation and output of pertinent vehicle/road descriptive parameters which are vehicle speed, traffic volumes at various service levels, road life to failure, and maintenance requirements.

3. The empiricisms in the VRCAMS structural and traffic volume/capacity modules provide for computations of existing conditions and the life expectancy of those conditions, respectively. Inherent in these computations, because of the "failed" versus "unfailed" definitions used, is the implication that a given compatibility level will exist until sudden failure. Since it is known that compatibility conditions change with time and traffic, a sixth module was developed for the VRCAMS that treats all output parameters as variables of a function of traffic and time. This deterioration analysis module uses functional deterioration of a road to show relationships between roughness and traffic, and between speed and roughness. This in turn provides for

relating speed reduction with road deterioration. Deterioration analysis in this manner gives the VRCAMS the capability of not only computing present conditions but also predicting future vehicle/road compatibility. The need to field-validate this sixth module gave rise to the need to conduct field tests to gather deterioration information.

4. Additionally, exchanges of information with the U. S. Department of Agriculture Forest Service (FS) showed that the need for deterioration analysis capabilities was mutually shared. The FS has a need to assess construction and maintenance costs on roads and trails that are constructed for the national forests and other purposes. Since public law provides that road construction and maintenance costs can be shared by commercial users, the FS must determine how these costs should be allocated. It was felt that this need of the FS could be met by the development of deterioration analysis techniques that would provide for assessing the road deterioration caused by given vehicle types. The specific application of the results of such studies would be in an investment strategy model now under development by the FS. The first generation system contains three principal subsystems, one of which is a maintenance cost module. Road deterioration is a vital part of this module.

5. Improved pavement analysis procedures being developed at WES also point to the need for a deterioration analysis system. These analytical systems, using multilayered elastic theory and being predictive of performance, rely on relationships of pavement deterioration versus environment and traffic.

6. In order to meet these common needs, the FS and WES agreed to certain field tests to provide a portion of the data needed to develop a deterioration analysis system. The conduct of such field tests was made possible by the advent of an intensive log-hauling operation in the Stanislaus National Forest near Sonora, California. A forest fire in the summer of 1973 killed trees in an area covering over 20,000 acres.*

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 6.

Successful salvage operations for about 200 million board feet (mbf) of timber dictated moving the usable logs during the summer and fall of 1974. This timber-hauling operation provided the opportunity to monitor paved, gravel, and unsurfaced roads for deterioration as they were being subjected to frequent heavy truck traffic. Tests that appeared likely to accomplish the desired results were initiated in the early summer of 1974 and completed in October 1974.

Purpose

7. The purpose of this investigation was to collect all data possible on a roadnet that would upon analysis provide for initial and partial development of deterioration relationships for roads subjected to vehicle traffic that could be used in the deterioration analysis module of the VRCAMS and in the investment strategy model. In addition, the establishment of a testing procedure for future use in collecting deterioration data was proposed. The collection of data pertinent to vehicle speed versus roughness to validate portions of the mobility and ride dynamics module of the VRCAMS was also intended.

Scope

8. This investigation was a combined effort by elements of WES and the FS. The chief efforts were planning and conducting tests to obtain deterioration data on the roads of the Stanislaus National Forest during the summer and fall of 1974. These data were undertaken to develop preliminary deterioration relationships; the results were applied to the VRCAMS and are being applied to the investment strategy model and other computational systems.

9. This report describes the field tests and data collected. It presents the data analyses and the resulting deterioration relationships. Appendix A describes the deterioration analysis module of the VRCAMS and its utilization of deterioration relationships. Applicability of deterioration relationships to the investment strategy model will be

reported under the auspices of the FS, while results of validation of the mobility/ride dynamics module of the VRCAMS will be published in subsequent reports by other elements of WES.

10. As previously mentioned, this study was not intended to be a complete effort in pavement deterioration analysis, but was intended to be the first in a series of studies to ultimately develop comprehensive deterioration analysis capabilities. This report therefore gives recommendations for future work based upon the current state of the art and lessons learned from this study.

Definitions of Terms

11. For clarity, definitions of certain terms as they are used in this report are as follows:

- a. Road: A horizontal structure consisting mainly of a traveled way, shoulders, and drainage facilities and intended as a route of travel for ground vehicles.
- b. Unsurfaced roads: A road whose surface consists only of materials naturally existing at the site, usually constructed with earth-moving equipment by grading, leveling, and drainage operations.
- c. Aggregate surfaced road: A road having a course of pit run crushed aggregate on the surface to improve the wearing and load-carrying capability.
- d. Flexible pavement surfaced road: A road consisting of an asphaltic concrete surfacing and a granular base course above the subgrade to provide a dustproof and waterproof wearing surface and to improve load-carrying capability.
- e. Primary road: A single road, usually gravel surfaced or flexible pavement surfaced, that provides sole or primary access to the area of operation.
- f. Secondary road: Any road leading from the primary road to parts of the area of operation that does not sustain volumes of traffic as high as the primary road.
- g. Tertiary road: An unsurfaced road, usually short (≤ 1 mile), that provides access from a secondary road to a specific operational location such as a loading area or a water point.

PART II: TESTS AND OBSERVATIONS

Test Area

Location and description

12. The Stanislaus National Forest is in the Sierra Nevada mountain range approximately 125 miles east of San Francisco, California. One of the two areas of the Stanislaus National Forest where testing was performed was subjected to intensive use by logging traffic while the other area sustained only light recreational traffic. The principal test area was located on the primary road that ran from the timber sale area toward the lumber mills and/or the secondary roads in and adjacent to the timber sale area. This primary road, designated by the Forest Service as 1N04, will be referred to in this report by its local name, Cottonwood Road. Cottonwood Road begins in Tuolumne, California, and runs approximately 35 miles eastward to Cherry Lake. The maintenance of the first 3 miles of Cottonwood Road was the responsibility of Tuolumne County since this section was outside of the National Forest boundary. The remaining part of Cottonwood Road is entirely within the National Forest. Numbered mileposts were located at 1-mile intervals beginning with milepost zero, around the middle of the county-owned section of Cottonwood Road, and running to milepost 32, about half a mile west of Cherry Lake. A general layout of Cottonwood Road along with some secondary roads is shown in Figure 1. Cottonwood Road contains sharp curves with grades up to 8 percent and lies in mountainous terrain consisting of weathered soils formed on igneous parent rock. Eastward from mile zero on Cottonwood Road, the grade runs generally uphill until it reaches a crest around mile 13 then goes downhill until it levels at the bridge over the Clavey River at mile 17.7. Cottonwood Road is then relatively flat between the Clavey River Bridge and the Reed Creek Bridge at mile 21.4. From there the grades are generally uphill to about mile 30. The road then runs downhill the last 2-1/2 miles to Cherry Lake.

13. Numerous secondary roads having various widths and surface

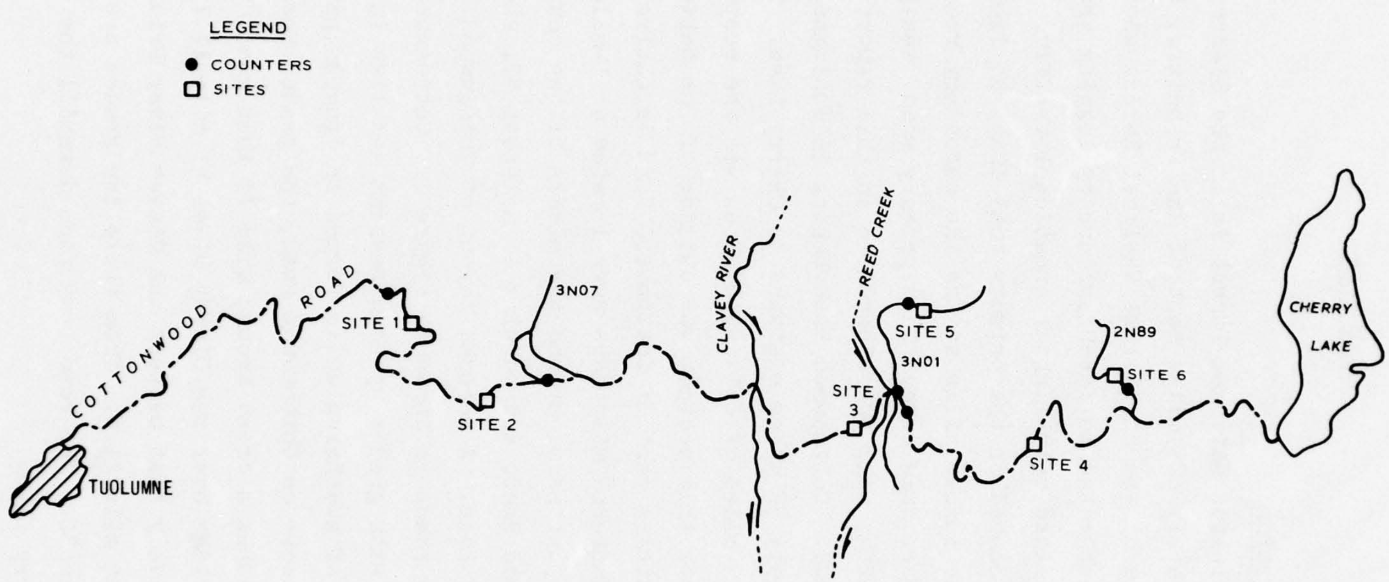


Figure 1. General layout of testing area

types intersect Cottonwood Road. The two feeder roads utilized in these tests were 3N01 North which entered Cottonwood Road at mile 21.8 and 2N89 which entered Cottonwood Road at mile 27.7.

14. The test area subjected to light recreational traffic was Herring Creek Road which intersects California State Highway 108 about 2 miles northeast of Strawberry, California. This road is approximately 20 miles north of the Cottonwood Road at Cherry Lake.

Test sites

15. General observations of traffic, maintenance, and construction were made over the entire area with specific testing being conducted at seven individual sites. The testing and observation period began 6 May 1974 and ended 29 September 1974. There were four test sites on Cottonwood Road and one site each on 3N01 North, 2N89, and Herring Creek Road. The general location of each site in the log-hauling area is shown in Figure 1. Site 1 was on Cottonwood Road, 200 ft west of milepost eight; site 2 was at mile 12.5. Both of these test sites had flexible pavements. Photo 1 shows site 1 at the beginning of the test period while Photo 2 shows site 1 after an asphalt overlay. Site 2 is depicted in Photo 3. Site 3, located at mile 20.5 between Clavey River and Reed Creek, was originally unsurfaced as shown in Photo 4. Photos 5 and 6, respectively, show site 3 after the base had been placed and after an asphalt surface had been added. Site 4 was 600 ft west of milepost 25 and, as shown in Photo 7, had an aggregate surface at the beginning of the test. Site 5 was on the aggregate surfaced 3N01 North about 2 miles north of the Cottonwood Road. Photo 8 shows the aggregate surface on site 5 at the beginning of the tests while Photo 9 shows the depth of the aggregate on site 5 in an exposed cross section at the edge of the road. Photo 10 was taken after a dust-oil layer had been applied to site 5. Site 6 in Photo 11 was about 1 mile north of Cottonwood Road on 2N89 which was unsurfaced. Site 7 (Photo 12) was on Herring Creek Road about 2 miles east of Highway 108. Figures 2 through 8 give plan and profile views of each of the seven test sites.

16. Sites 1 through 4 on Cottonwood Road generally experienced

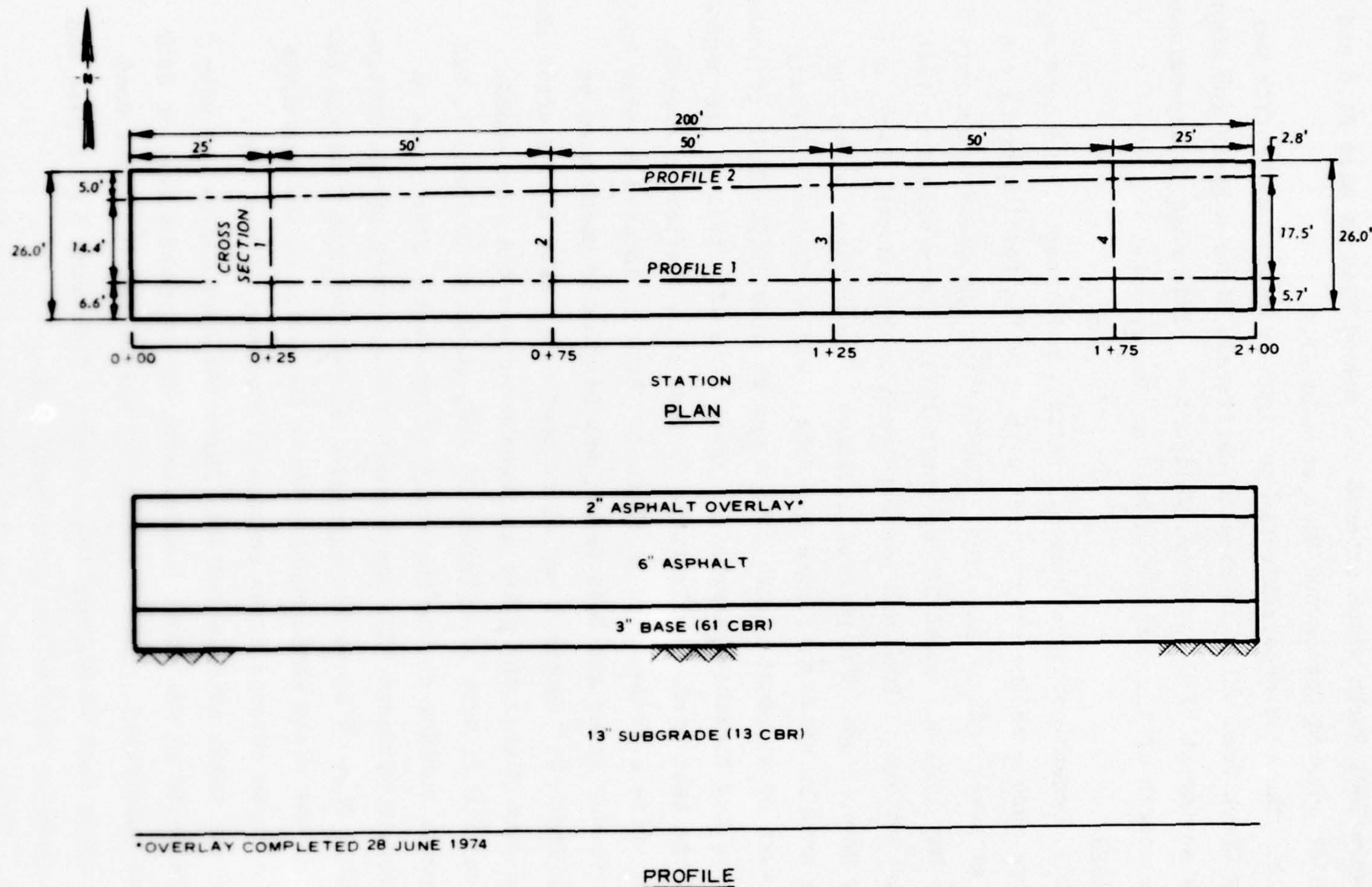


Figure 2. Test site 1, Cottonwood Road

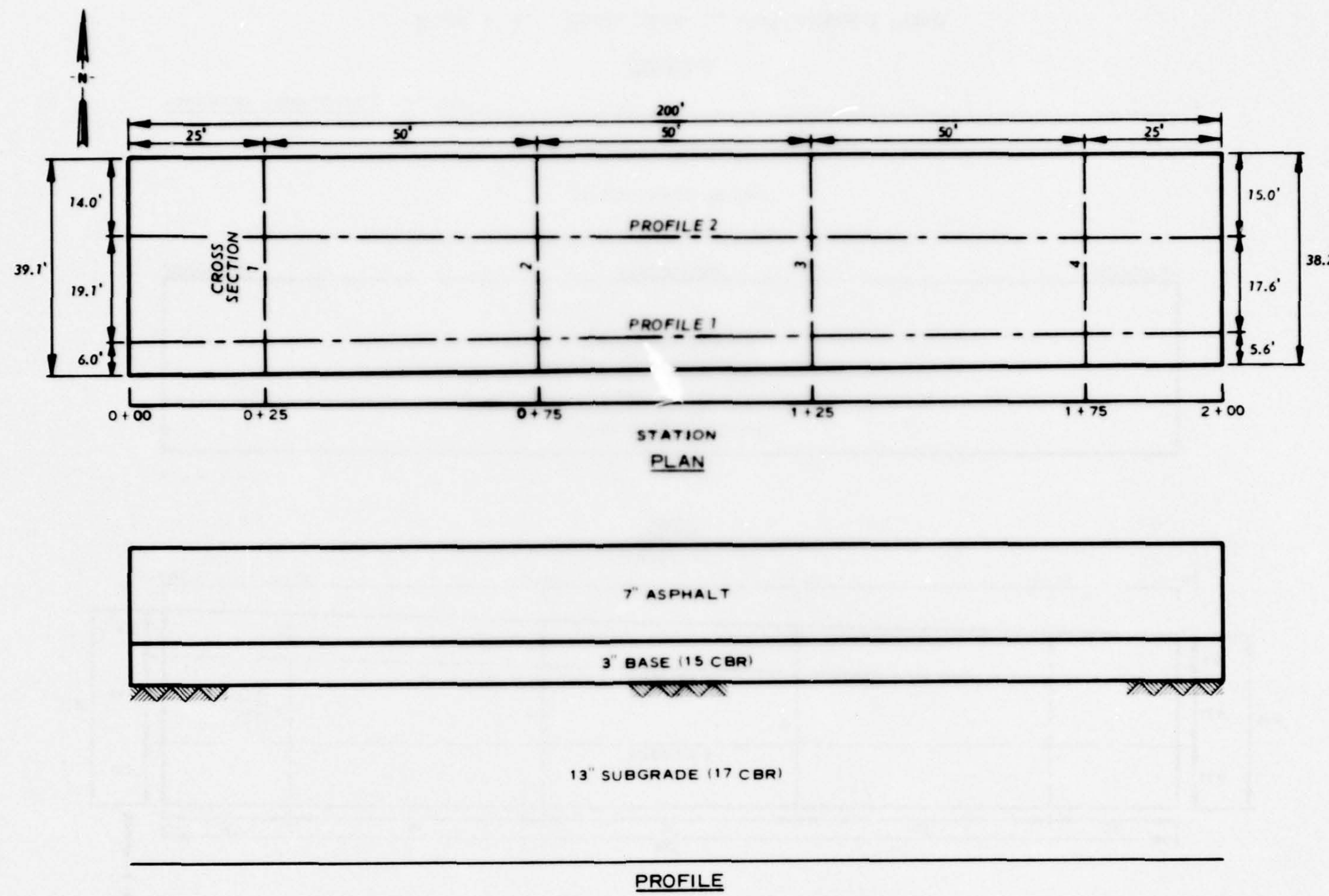
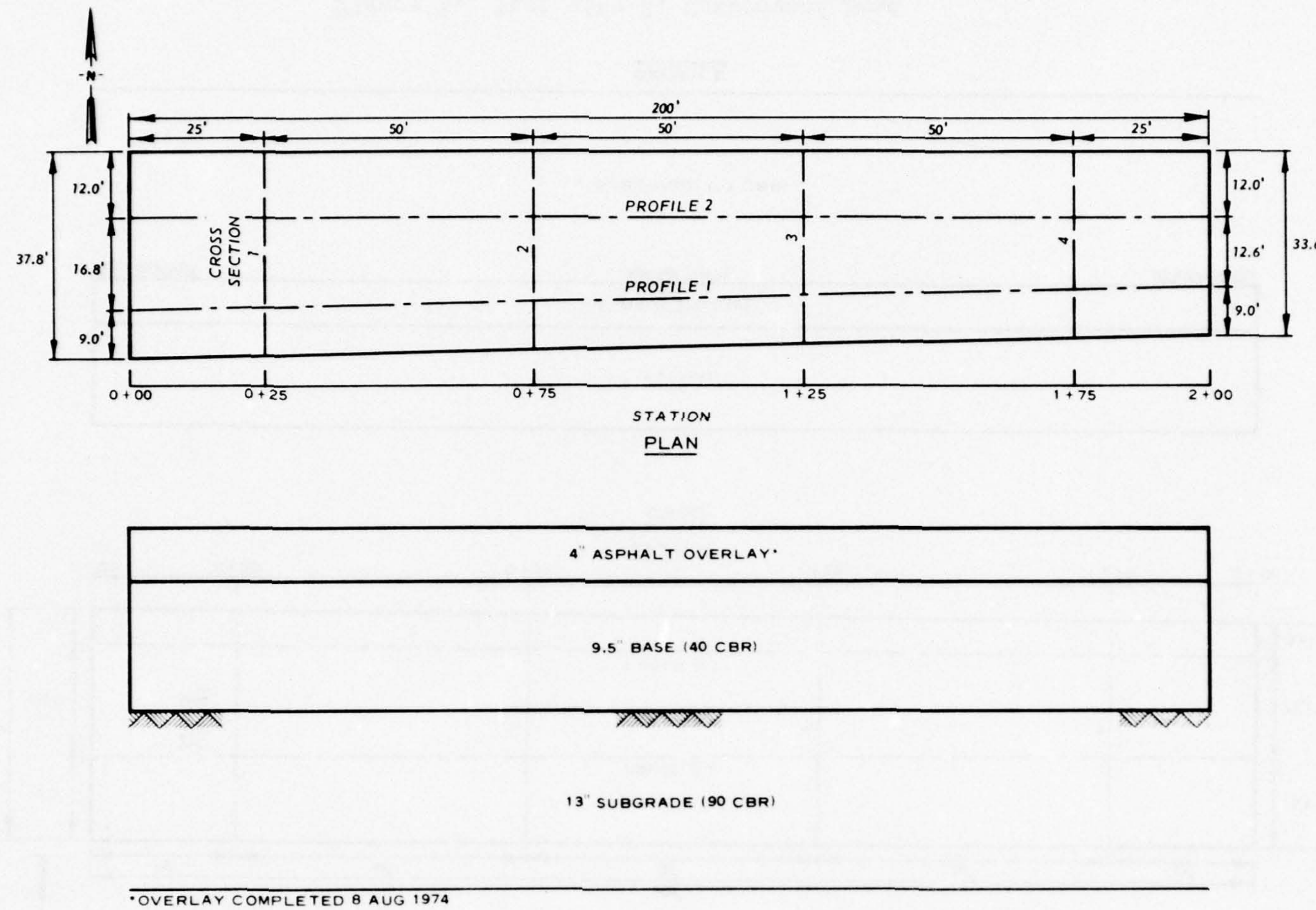


Figure 3. Test site 2, Cottonwood Road



PROFILE

Figure 4. Test site 3, Cottonwood Road

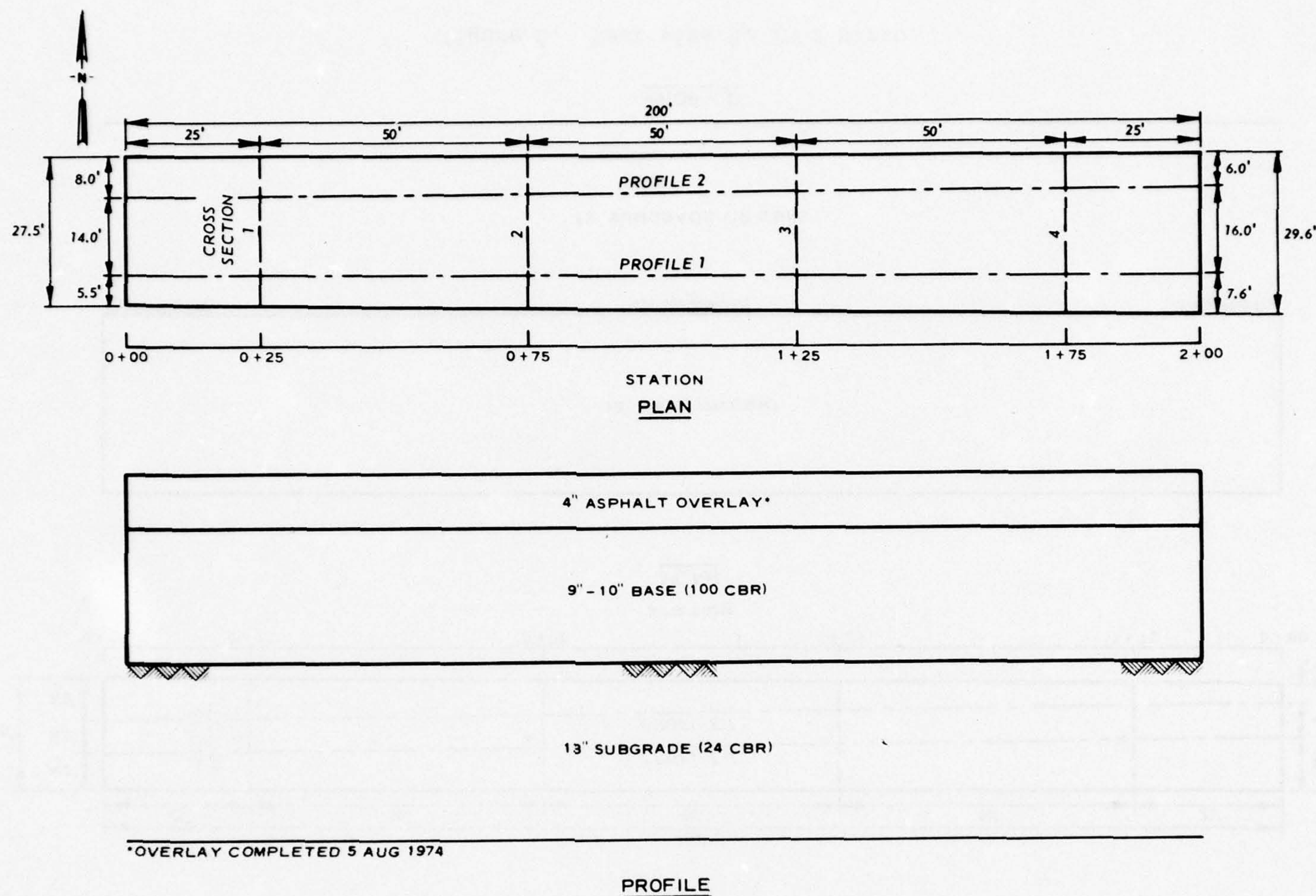


Figure 5. Test site 4, Cottonwood Road

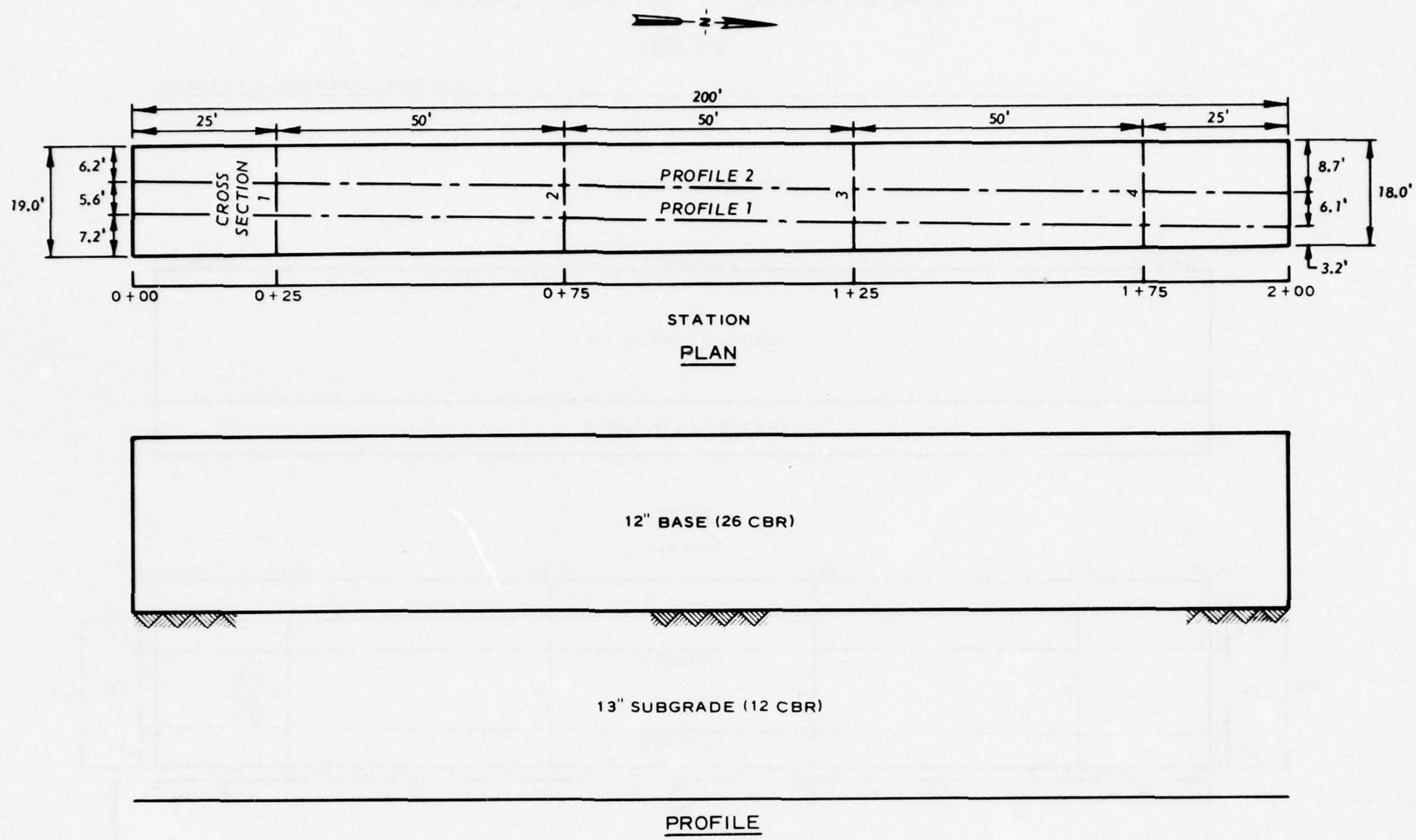


Figure 6. Test site 5, 3N01 North

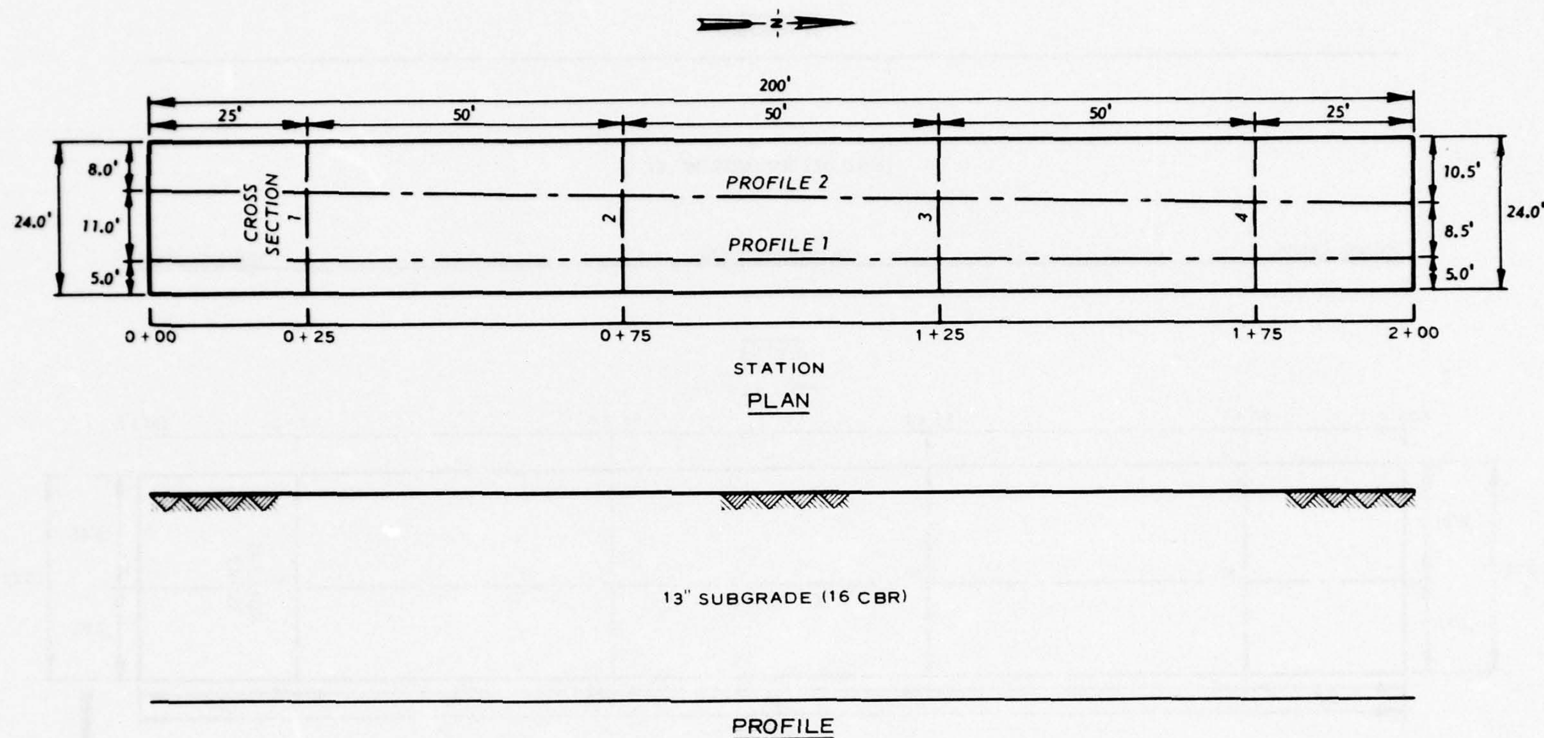


Figure 7. Test site 6, 2N89

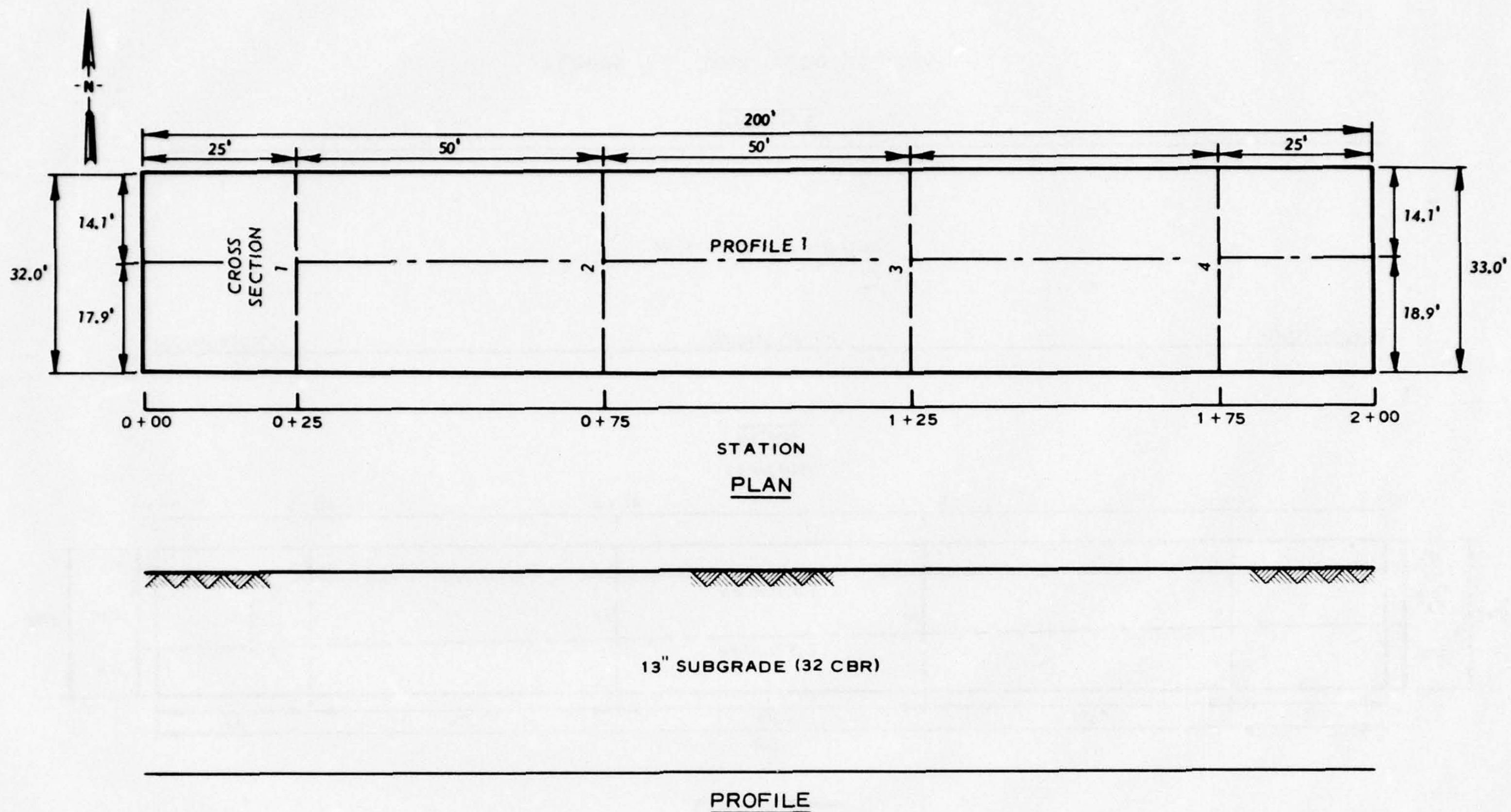


Figure 8. Test site 7, Herring Creek Road

heavy logging traffic approximating 300 trucks per day. Sites 5 and 6 were on feeder roads having a lower volume of logging traffic than the sites on Cottonwood Road. Site 7 was outside the logging area with the majority of its traffic being recreational.

Construction

17. Cottonwood Road was constructed in 1965. The section between milepost one and the Clavey River Bridge had an asphalt surface at the beginning of the test. This asphalt pavement, varying in thickness from 4-1/2 to 10 in., was placed in the fall of 1973. The section of Cottonwood Road between the Clavey River Bridge and milepost 30 was paved with a 4-in. asphalt surface in the summer of 1974 during the WES observation period. The primary paving operation, which involved placing the asphalt in two layers, began 15 July and ended 8 August, a total of 19 workdays. The asphalt surface overlaid an aggregate base of varying thickness dependent upon the strength of the subgrade. The Cottonwood Road east of the Reed Creek Bridge had most of the base in place at the beginning of the testing period with some being added later. In the 4-mile section between the Clavey River and Reed Creek that included site 3, all of the base material was placed after the WES observation began.

18. Typical sections of the test sites on Cottonwood Road showing the asphalt and base thicknesses at the end of the field tests are presented in Figures 2 through 6. The dates of the placement completion for the asphalt surfaces on sites 3 and 4 as well as the asphalt overlay on site 1 are noted in these figures. The subgrade of the section between the Clavey River and Reed Creek required extensive scarifying and blading by a motor grader to achieve the design grade before the base was added. This construction continued for some time after the WES observation began. During the construction period there were several rockslides on this 4-mile road section which had to be cleared.

19. The construction operation and the log-hauling operation were conducted simultaneously on Cottonwood Road causing some delay to both operations. Since the log trucks were running constantly over the base course, the base required final grading prior to paving. This

final grading operation usually occurred about one day prior to placing the binder course of asphaltic concrete.

Upgrading

20. During the testing period several other construction activities were conducted in addition to the asphalt paving. A dust-oil layer was placed on the aggregate base on sections of Cottonwood Road to reduce dust during the period prior to paving. Site 4 was in one of the sections that received an oil application. Since there was a relatively long time interval between placement of the oil layer and the asphalt paving, much of the oil treatment was rendered ineffective by the heavy traffic, especially in curved sections of roadway. Before the oil was placed, the surface wear caused by the traffic was similar over all portions of the base surface. However, after the oil layer had been placed, the base that was exposed when sections of the oil layer wore off exhibited more wear than the surrounding surfaces. This resultant partial oil surfacing and consequent nonuniform wear created severe potholes that made the road rougher than it was before the oil layer was applied.

21. During the summer a log-loading area was constructed adjacent to site 4. In building this loading area some of the aggregate base on Cottonwood Road was excavated and replaced. Asphalt curbs were also built on several sections of Cottonwood Road including the parts paved in 1973 and 1974. An asphalt curb was constructed along the eastbound lane of site 3.

22. Toward the end of the summer most of the secondary feeder roads were given an aggregate, oil layer, or asphalt surface. During the summer, sites 6 and 7 experienced no construction activities, but a dust-oil layer was placed on the aggregate surfaced 3N01 North on two different occasions. In preparation for the oil layer, 3N01 North including site 5 was bladed extensively by a motor grader. Site 5 was bladed on 30 July for the first time since the beginning of the test period. From 5 to 9 August, 3N01 North was scarified, bladed, and watered. On 10 August, 3N01 North was closed to traffic and a thin oil layer was applied. This oil layer was described by the contractor as

MC-70 with a thickness of about 0.25 in. An observation made on 12 August showed scattered patches where either the oil layer was not placed or had broken after traffic. On site 5 there was an approximately 35-ft patch of exposed aggregate in the east wheel path. For a week or so after the application of the oil layer, the log hauling was limited to about two trucks to help compact the oil layer. Even this relatively light traffic broke large areas of the oil layer, particularly in the curves. Loose rocks scattered over the oil layer remaining in place because the oil layer had been unable to hold down these 2- to 3-in.-diam rocks that had popped out when exposed to traffic. Photo 10, taken around the first of September, shows the deterioration of the oil layer on site 5. The apparent reason for the failure of the oil layer to remain in place was the high percentage of coarse gravel in the underlying aggregate base that had been placed before the testing period began.

23. On 26 August, 3N01 North had some slight blading done on the rougher sections. The western edge of the pavement in the middle of site 5 was one of the places bladed. The bladed area was outside (west) of the west wheel path. On 30 August, 3N01 North was bladed again and watered.

24. On 6 September a second oil layer was placed on 3N01 North after the road was bladed and watered. Insufficient curing time prior to use in addition to excessive richness and thickness caused the oil layer to shift. Although the road was closed on 6 September, it was opened to recreational traffic the next day. On 8 September, the oil treatment was still sticky, peeling off in most areas. The oil layer remained only where the previously applied oil layer was still in place. The oil layers continued to deteriorate for the rest of the testing period.

25. On 24 August an oil seal was placed on the asphalt pavement of Cottonwood Road from the Clavey River Bridge to the end of the asphalt pavement at mile 30. The rest of Cottonwood Road from mile one to the Clavey River was given an oil seal on 17 September.

<u>Maintenance</u>

26. During the testing period some maintenance was performed on

the asphalt surfaced, aggregate surfaced, and unsurfaced roads. There were several small localized failures requiring extensive patching in the asphalt pavement of Cottonwood Road. These were located mainly in the downhill westbound lane between mile 4 and mile 9. Two of these failures are shown in Photos 13 and 14. Most of these localized failures were slippage failures caused by the loss of bond between the surface layer of asphaltic concrete and the underlying asphalt. The maintenance consisted primarily of excavating and replacing the damaged material in the area surrounding the failure. Site 1 had one failure area in the westbound lane that was repaired on 20 and 21 May. Another slippage failure was observed in the eastbound lane of site 1 on 7 June. The section of Cottonwood Road having the most failures was given a 2-in. asphalt overlay on 28 June. This 1.2-mile section, which included site 1, was located between miles 6.9 and 8.1.

27. Until these sections were paved, maintenance was performed almost daily on the aggregate surfaced sections of Cottonwood Road. Due to the dry conditions during the summer and the heavy daily traffic, the unpaved sections of Cottonwood Road were sufficiently dusty to hinder the log-hauling traffic and create a safety hazard. As a preventive measure to reduce dust the road was watered frequently. Another form of maintenance conducted on the unpaved portions of Cottonwood Road was occasional grading to remove irregularities caused by the traffic.

28. Site 5 on the aggregate surfaced 3N01 North experienced no maintenance during the testing period while site 6 on the unsurfaced 2N89 experienced constant grading and watering. This difference in maintenance was due to the difference in surface types and the difference in contractor maintenance practices. The lumber company that would have provided maintenance on 3N01 North was primarily responsible for placing the aggregate base on Cottonwood Road between the Clavey River and Reed Creek. Thus, until their construction activities on Cottonwood Road were finished they could not divert equipment to 3N01 North. As soon as the placement of the aggregate base on Cottonwood Road was completed, the contractor began grading 3N01 North in preparation for the oil layer that was placed on 10 August.

29. In contrast to 3N01 North, almost all of the other secondary roads in the log-hauling area had at least some type of maintenance during the testing periods. Of all the secondary roads observed, 2N89 probably had the most maintenance. After site 6 on 2N89 was selected as a test site on 21 June, the observation of the maintenance on 2N89 began. The maintenance on 2N89 consisted mainly of grading the road as shown in Photo 15, and watering the road as shown in Photo 16. From the initial observation until the end of July, site 6 was graded from two to four times a day two days a week. The grading procedure consisted of one pass over and back the entire length of 2.2 miles. Occasionally during this round trip, the motor grader would back up and regrade parts of the road. Based on observations made during this period, there was an average of six passes per day by water trucks. The number of water truck passes and hence the wetness of the road varied considerably from day to day. The purposes of the water trucks were to keep the road wet when it was being graded and reduce the dust caused by the traffic.

30. About 24 July a new motor grader operator was assigned to 2N89 and a few adjacent secondary roads. This operator did all of the grading on 2N89 for the rest of the testing period. With the change of motor grader operators there was also a change of maintenance procedure. Instead of the entire road being graded with a series of long passes, 2N89 was divided into four separate sections that were graded one at a time with four to eight passes per section. Of the four sections, the section that underwent the most grading contained site 6 which was graded about four times a week. During this portion of the test period there appeared to be more coordination between the grading and watering activities since the water trucks and the motor grader both operated simultaneously on the same section of 2N89. Keeping the road wet while being graded rendered the grading operation more effective. The number of water truck passes on site 6 increased during this period to about 10 or 12 per day. This number varied depending upon the number of water trucks operating on 2N89 and the distance the water trucks had to travel to the water supply, as well as other considerations.

31. At times 2N89 was watered so heavily that lighter vehicles

experienced traction difficulties on some of the steeper grades. Evidently, as long as the water trucks were on the job, they continued to run whether or not the road actually needed further watering. Similarly, there were times when the motor grader unnecessarily graded the road. The contractor's reasoning appeared to be that as long as the maintenance equipment was available it was better to maintain the road continuously rather than wait for the road to deteriorate enough to require extensive maintenance. Usually the road deteriorated little between maintenance cycles. Since the rutting that occurred between cycles was minimal, light grading by the motor grader was sufficient in most cases.

32. The Herring Creek Road had one session of maintenance, being graded between 5 and 8 August. This maintenance on site 7 was conducted by FS personnel.

Traffic Counting and Evaluation

Counters

33. To measure the amount of traffic on the test sites, two types of battery-operated traffic counters were used. One was a Fisher-Porter magnetic loop counter in which a wire loop is placed a few inches below the road surface registering each vehicle as it passes through the magnetic field created by the loop. An attached strip recorder accumulates traffic volume at 1-hr intervals. A weakness of this type of counter is its failure to discriminate types of vehicles. Electric eye counters aided in solving this problem. This type of counter has a transmitter on one side of the road which sends a light beam across the road to a reflector which sends it back. Whenever a vehicle passes through the light beam it is registered by the counter. By setting the transmitter and reflector high enough, only the taller, heavy vehicles such as log and gravel trucks were counted. Occasionally the electric eye counted light vehicles such as recreational campers or pickup trucks carrying tall loads, but this was minimal. In contrast to the magnetic loop counters, the electric eye counters used a digital register.

Locations

34. A total of seven counters were used at various locations. There were two magnetic loop counters on Cottonwood Road, one at mile 6 and the other at mile 22, 200 ft east of the intersection of 3N01 North. For most of the testing period an electric eye counter was located at mile 13 on Cottonwood Road. This counter had been placed around mile 10, but was moved to mile 13 on 14 May. The count from the electric eye register represented all of the logging trucks and most of the heavy construction and maintenance vehicles that passed sites 1, 2, and 3 on Cottonwood Road. The count at mile 13 was not representative of the logging traffic on site 4 since there were several feeder roads carrying logging traffic which intersected Cottonwood Road between mile 13 and site 4. To measure the traffic on site 5, a magnetic loop counter was installed on 3N01 North about 500 ft north of Cottonwood Road, and an electric eye counter was placed at site 5 on 3N01 North. The mounted electric eye counter on site 5 is shown in Photo 17. A magnetic loop counter was located about 500 ft north of Cottonwood Road on 2N89 to count the vehicles passing site 6, while another magnetic loop counter was placed on the Herring Creek Road.

Procedures

35. Each traffic counter was read two to three times per week. For the magnetic loop counters the traffic volume at 0600 hr was read from the attached recorder. At the conclusion of the testing period the paper tapes on the strip recorders of the magnetic loop counters were computer processed by FS representatives. The resulting computer printout gave the accumulative traffic counts in addition to the date and hour each count was recorded. There were some errors in the dates listed on the computer printout, but by comparing the printout with the counter readings made in the field test, these inaccurate dates were corrected. The accumulative daily traffic was then computed using the corrected printout data.

36. Since the electric eye counters registered only a continuous traffic total, it was difficult to determine the traffic distribution over a given period of time. Attempts to have daily readings at

approximately the same time proved difficult because other work requirements conflicted with so arduous a schedule. Consequently, averages for each five-day work week were projected from two daily readings taken with appropriate time intervals during the week in question. Weekend traffic was determined by subtracting the reading at the end of a work week from the initial reading at the beginning of the following work week.

37. After the traffic data were sorted into daily and weekend traffic, they were classified according to vehicle type by the following procedure. For 3N01 North and Cottonwood Road the traffic measured by the magnetic loop counters and not by the electric eye counters was classified as consisting of light vehicles. Although mainly pickup trucks, this classification would also include passenger cars, jeeps, and motorcycles. Based on many manually counted traffic samples taken during the summer, the traffic measured by the electric eye counter was further divided into two groups, log-hauling trucks and medium vehicles. A typical loaded log truck is shown in Photo 18; a typical unloaded log truck is shown in Photo 19. The medium vehicle classification included gravel trucks, asphalt trucks, water trucks, motor graders, recreational campers, and trailer trucks carrying construction equipment. It was not necessary to establish counts for the different types of medium vehicles because there were so many types and the overall total was small compared with the number of log trucks. In addition, the critical lane on Cottonwood Road from a deterioration standpoint was the westbound lane on which the loaded log trucks traveled. The gravel and asphalt trucks were usually loaded on the eastbound lane and empty on the westbound lane. Site 6 on 2N89 did not have an electric eye counter, but it did have a magnetic loop counter which recorded all vehicular traffic. Based on the traffic sampling on 2N89, this total vehicle count was divided into two categories, log trucks and other vehicles. There were few gravel trucks and no asphalt trucks on 2N89 during the testing period. The only regular heavy-load traffic on 2N89 consisted of log and water trucks. Most of the other traffic consisted of pickup trucks. Since the traffic on site 7 was primarily

recreational with no log trucks, traffic samples were not made on this site.

38. Even though all counters should have operated continuously throughout the testing period, occasional breakdowns did occur. Batteries were the primary cause of failure in the magnetic loop counters. The large power drain of the magnetic loop counters caused the batteries to have a relatively short life. The percentage of vehicles detected gradually decreased as the batteries weakened beyond a certain voltage level. Since the counter would still be recording some vehicles, this gradual failure was difficult to detect. Consequently, some counters were working improperly for several days before the malfunction was detected and the batteries changed. To solve this problem, the batteries were subsequently checked frequently with a voltmeter and replaced when approaching the failure level. The electric eye counter at site 5 experienced no problems during the testing period although the electric eye counter at mile 13 on Cottonwood Road had two short intervals of inoperation. One interval occurred when the counter was moved from its previous location around mile 10; the other occurred when the reflectors were removed by vandals. The amount of traffic passing an inoperative counter was estimated from the traffic data for other dates.

Data collected

39. The traffic samples on sites 1 through 6 were taken on various days, at various times, and with various time intervals. The roads with less traffic required longer sampling time intervals to acquire sufficient data. For all six sites the traffic for any given day was classified according to the samples taken during the same relative time period. The weekly accumulative traffic data from the date of the initial testing at each site to the end of the testing period are summarized in Tables 1-6.

Surface Roughness

Cross sections and profiles

40. Several procedures were used to measure the road surface roughness of the test sites and the changes in roughness due to traffic.

One method was profiles and cross sections taken with a surveying level and level rod. Figures 2 through 8 show the general layout of the respective test sites and the locations of the cross sections and profiles. The sites were using conventional surveying station numbers beginning with station 0+00 and ending at station 2+00. Photo 20 shows site 1 being measured and marked off. The first six test sites had four cross sections covering the entire width of the road at 50-ft intervals and also had two parallel 200-ft profiles. Site 7 had four cross sections and only one 200-ft profile. Rod readings were taken at 2-ft intervals along the cross sections on sites 1 through 4 on Cottonwood Road and at 1-ft intervals along the cross sections on sites 5 through 7 on the secondary roads. Photo 21 shows typical cross-section measurements being taken on site 3. Rod readings were taken along the profiles every 5 ft on all seven sites. On Cottonwood Road the profiles were measured along the outside wheel path of both the east- and westbound lanes. Since sites 5 and 6 were on essentially one-lane roads, the profiles were along both wheel paths. Since the section of Herring Creek Road where site 7 was located was relatively flat and smooth, one profile was considered representative of the entire road. In addition, the wheel paths of site 7 were undefined due to the small amount of traffic.

41. The profiles and cross sections were taken at various times during the entire summer. The initial measurements on sites 1 through 5 were made during the week of 5 to 11 May. Site 6 was added on 21 June; site 7 had its initial measurement on 25 July. The final profiles and cross sections were made during the week of 22 to 28 September.

42. An effort was made to obtain the rod reading for each subsequent set of measurements at the same points on the road as the initial readings. This was necessary to accurately determine the change in the road surface. Therefore, the initial points were referenced with offset stakes placed well off the road. Although some of the offset stakes were disturbed by construction or logging operations, the initial points were reestablished with a satisfactory degree of accuracy. Cross-section data are graphically presented in Figures 9 through 15;

some representative profile data from each site are presented in Figures 16 and 17.

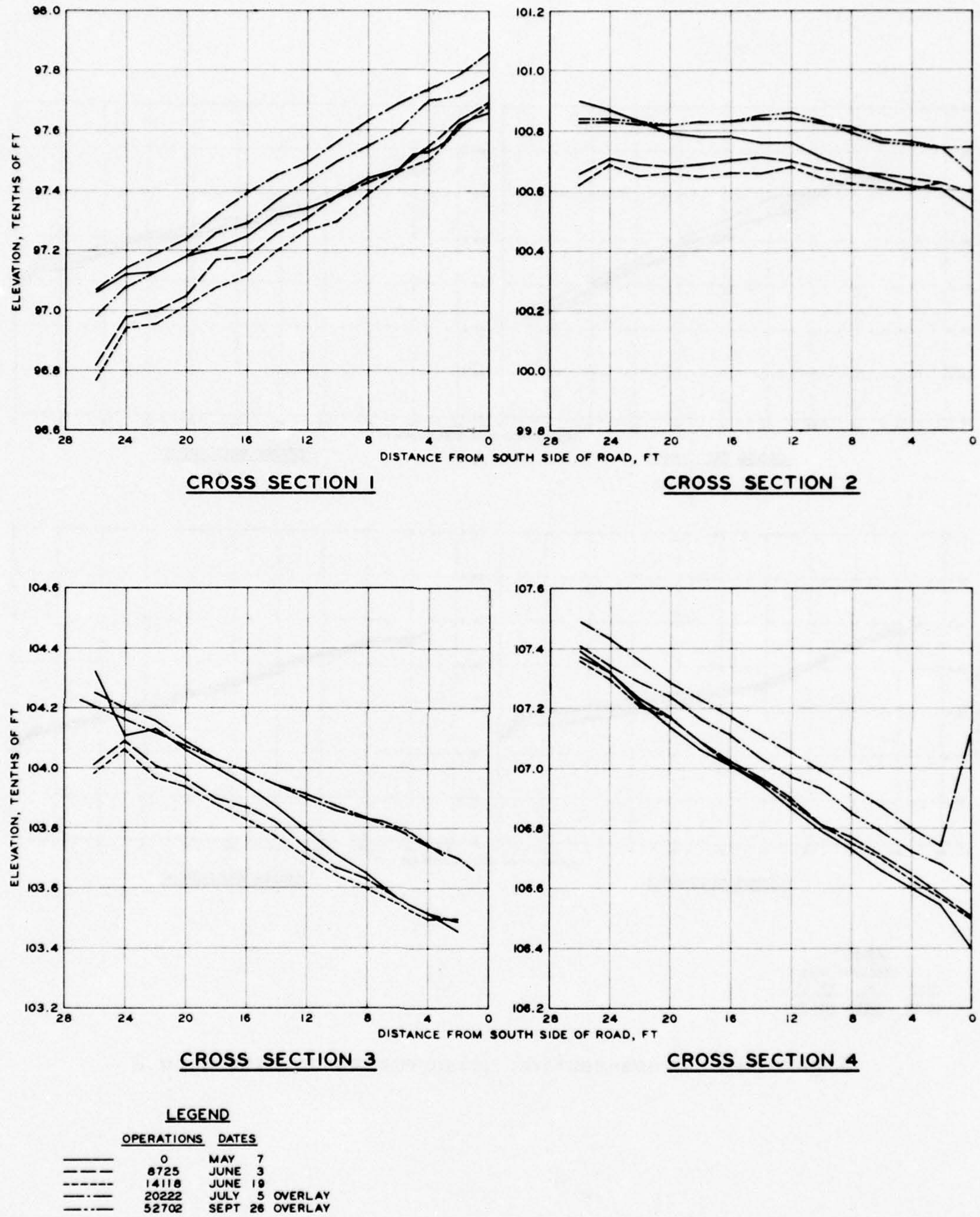


Figure 9. Cross-section measurements on test site 1

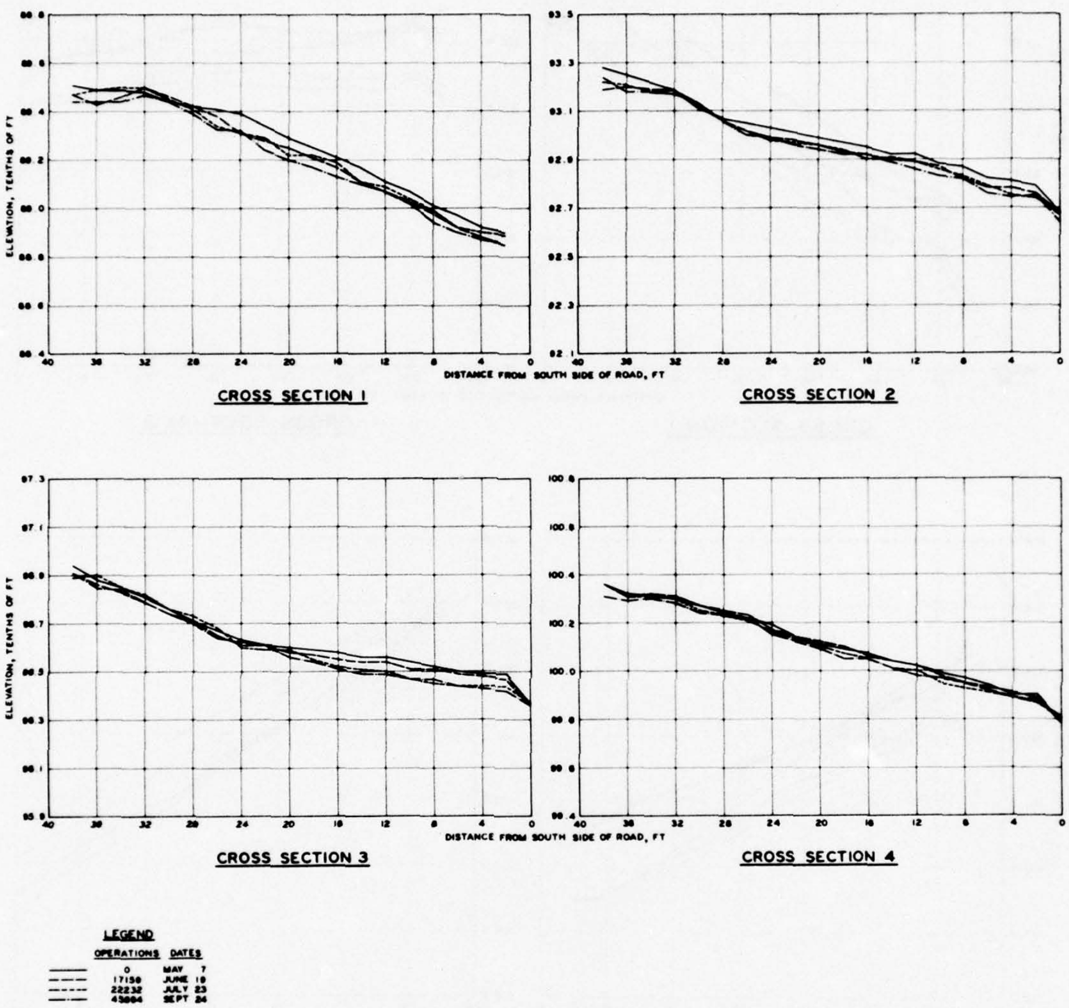


Figure 10. Cross-section measurements on test site 2

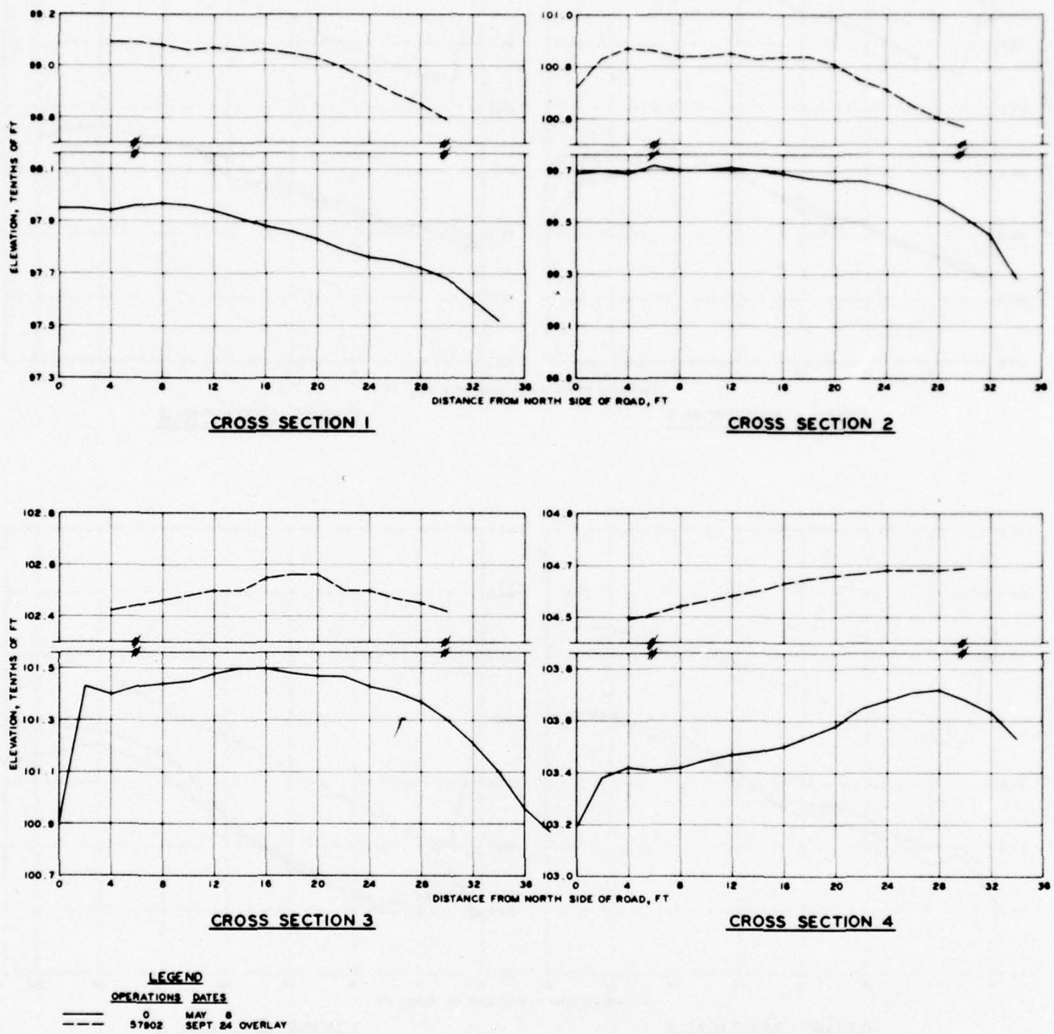


Figure 11. Cross-section measurements on test site 3

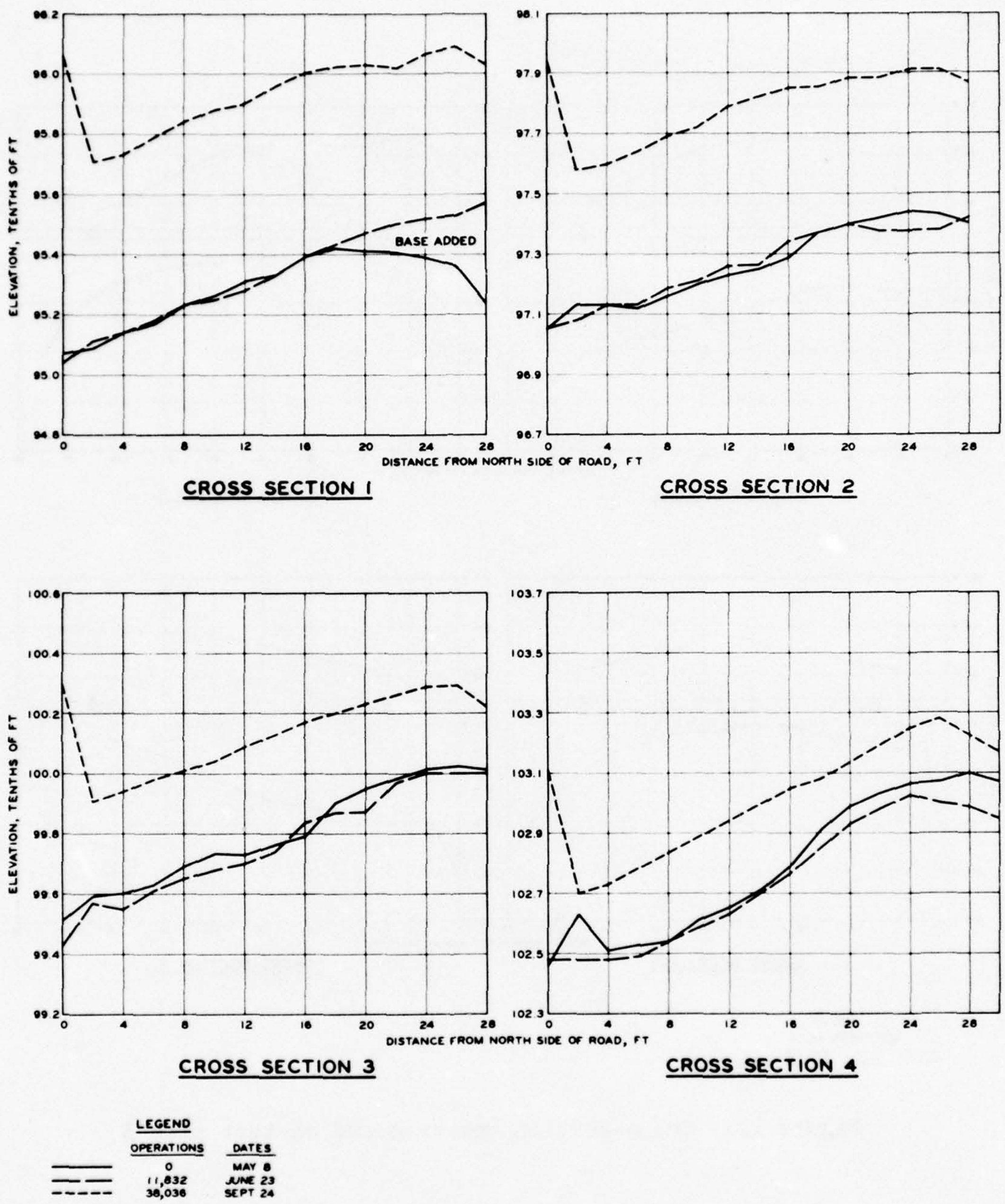


Figure 12. Cross-section measurements on test site 4

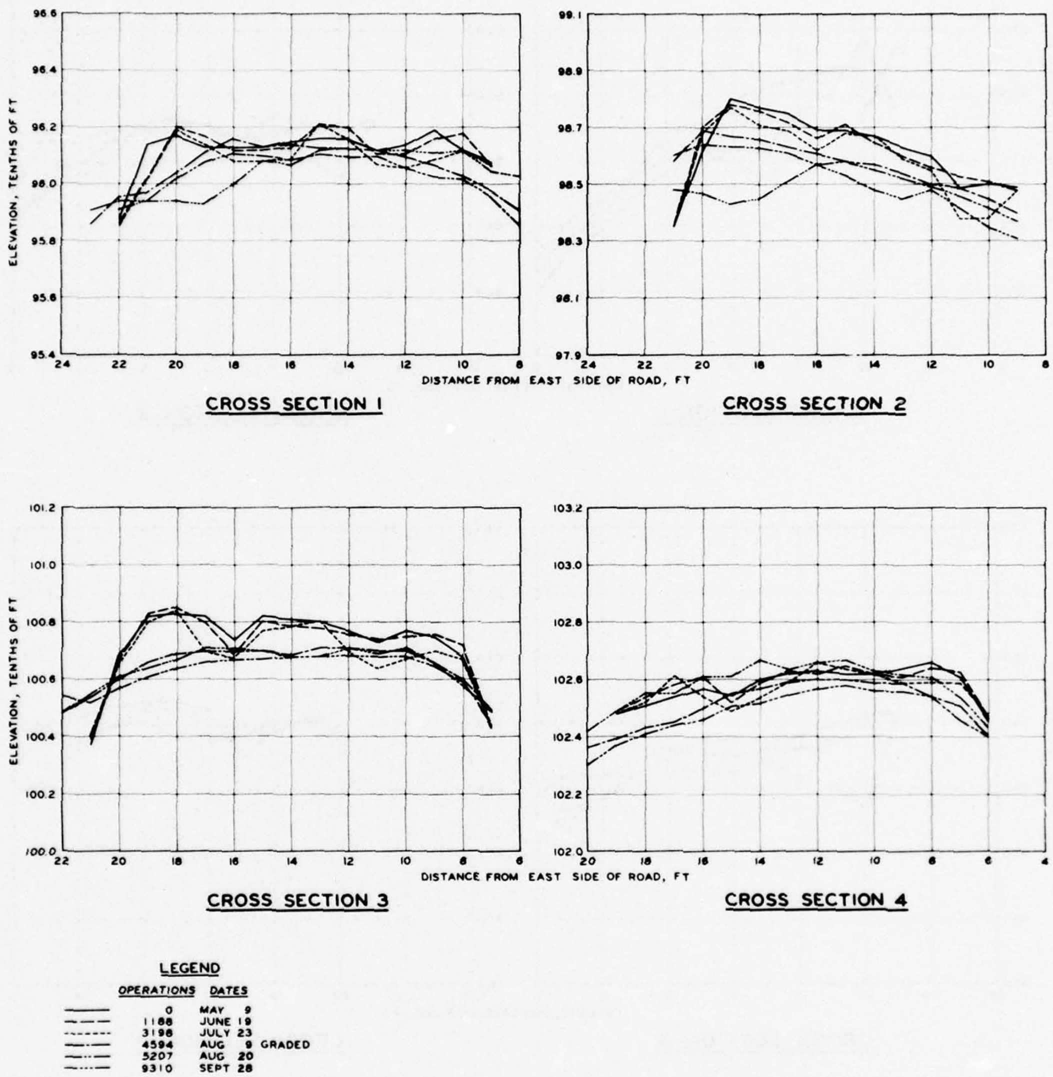


Figure 13. Cross-section measurements on test site 5

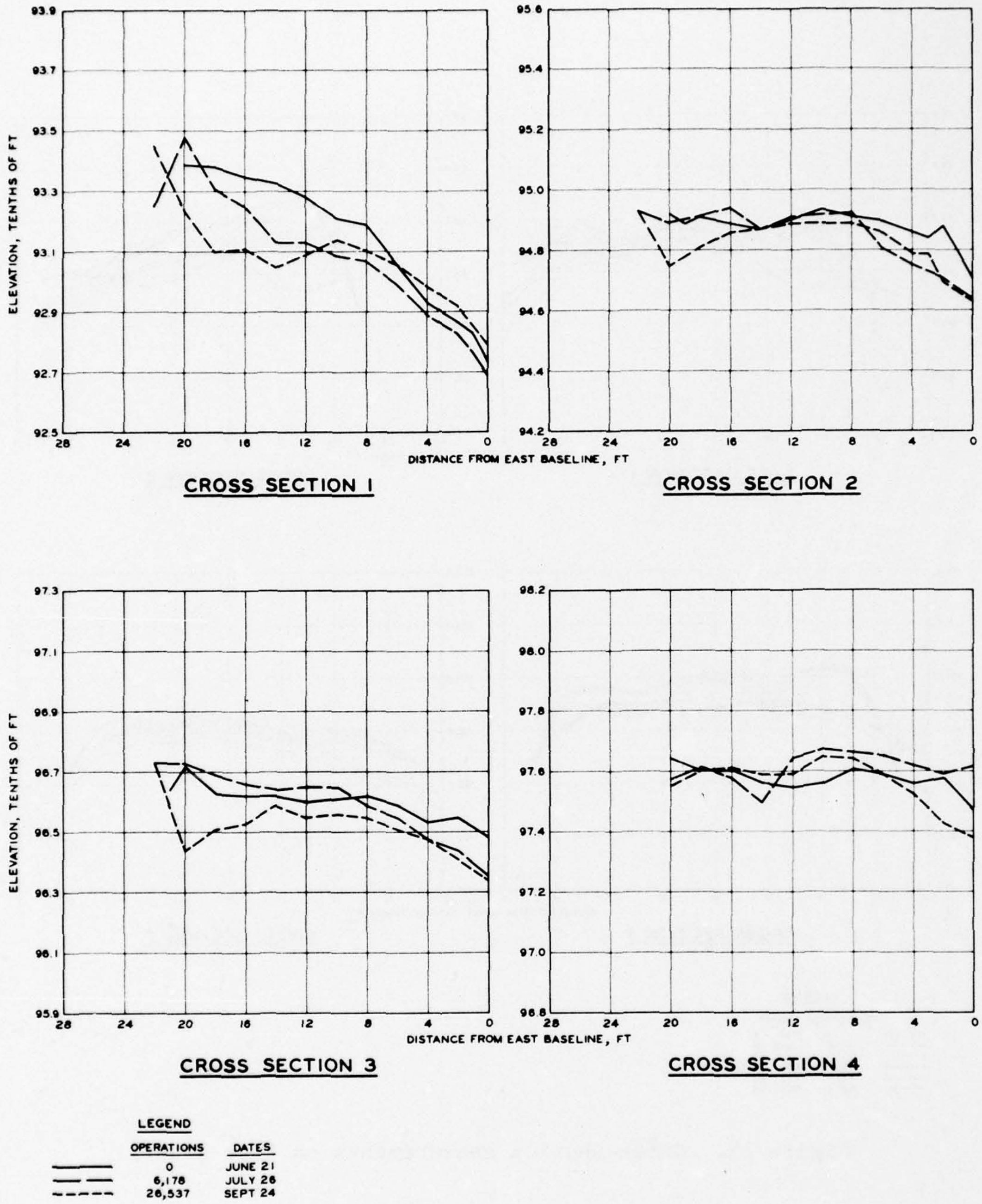


Figure 14. Cross-section measurements on test site 6

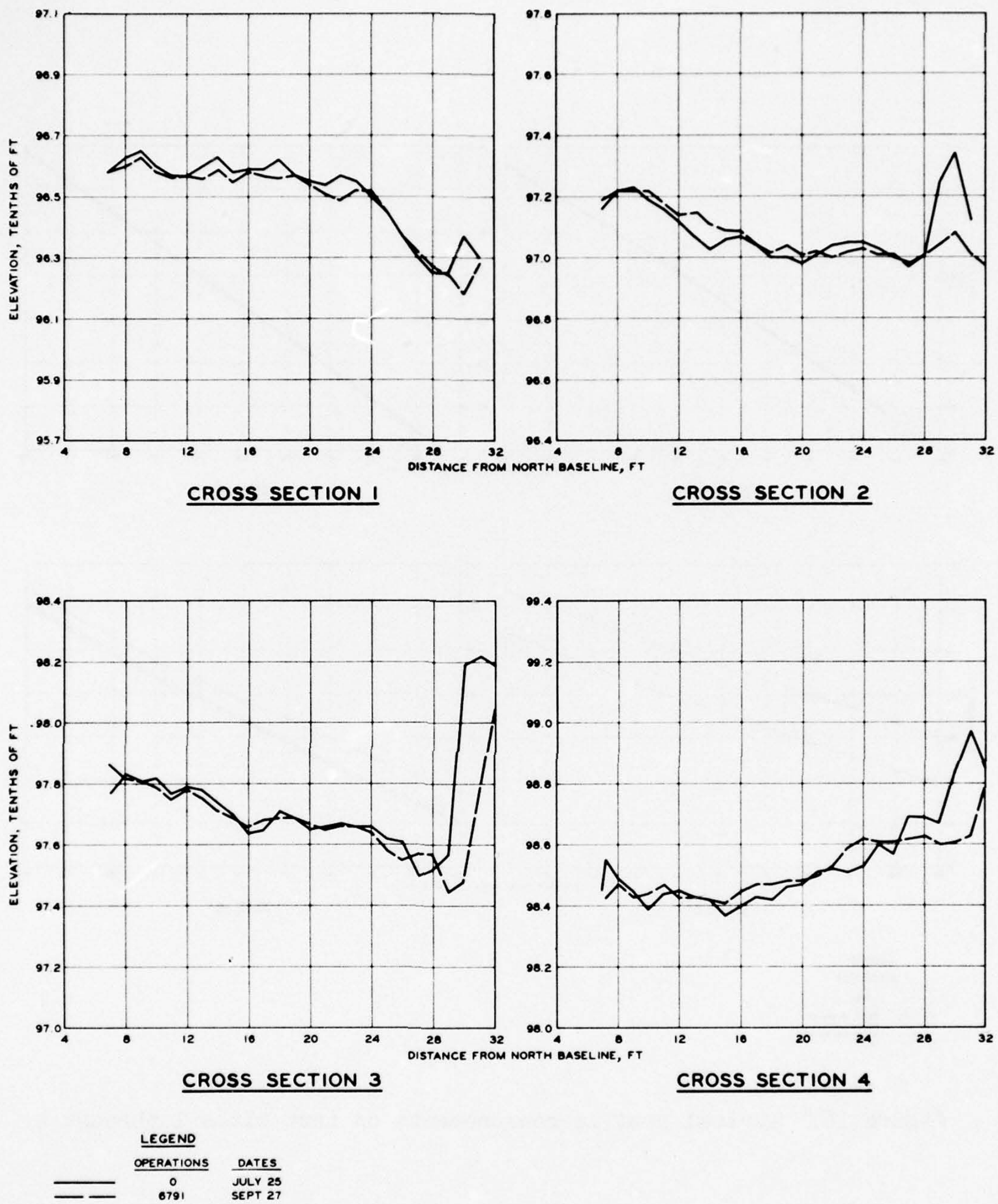


Figure 15. Cross-section measurements on test site 7

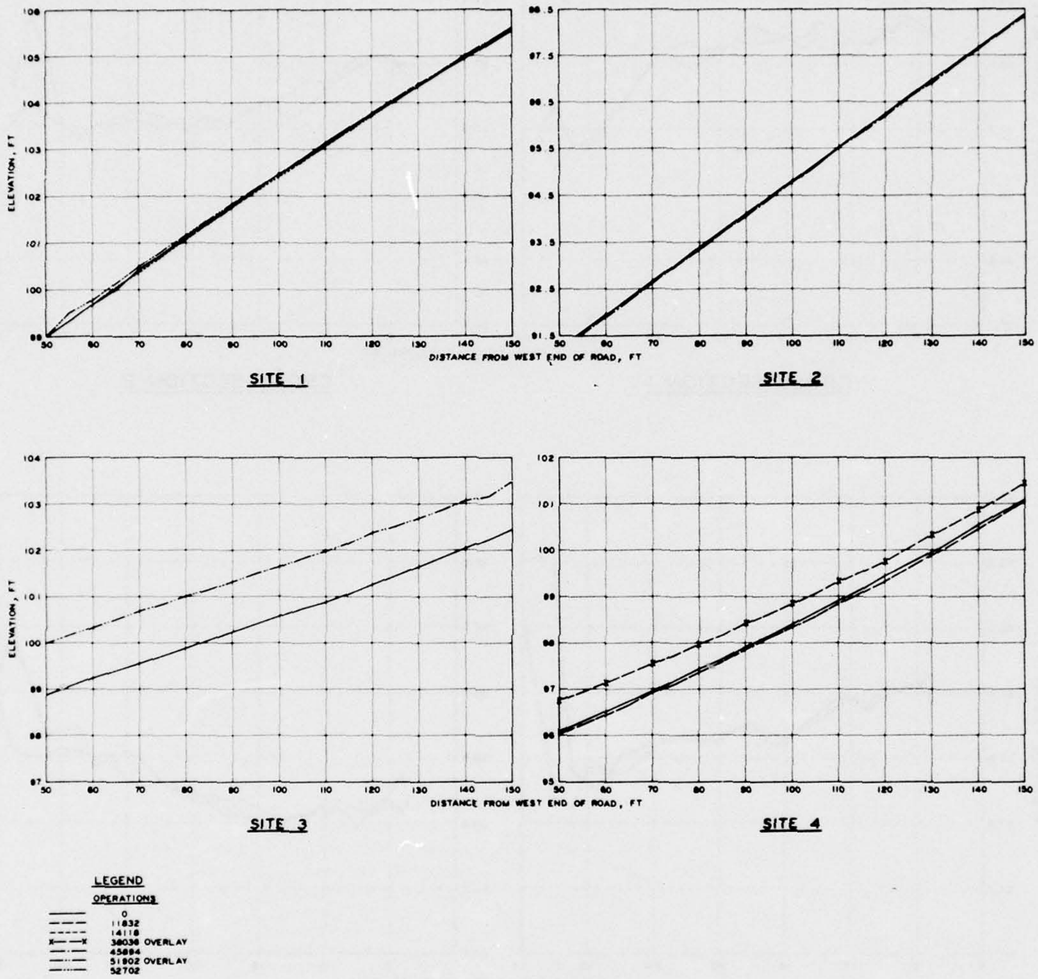


Figure 16. Typical profile measurements on test sites 1 through 4

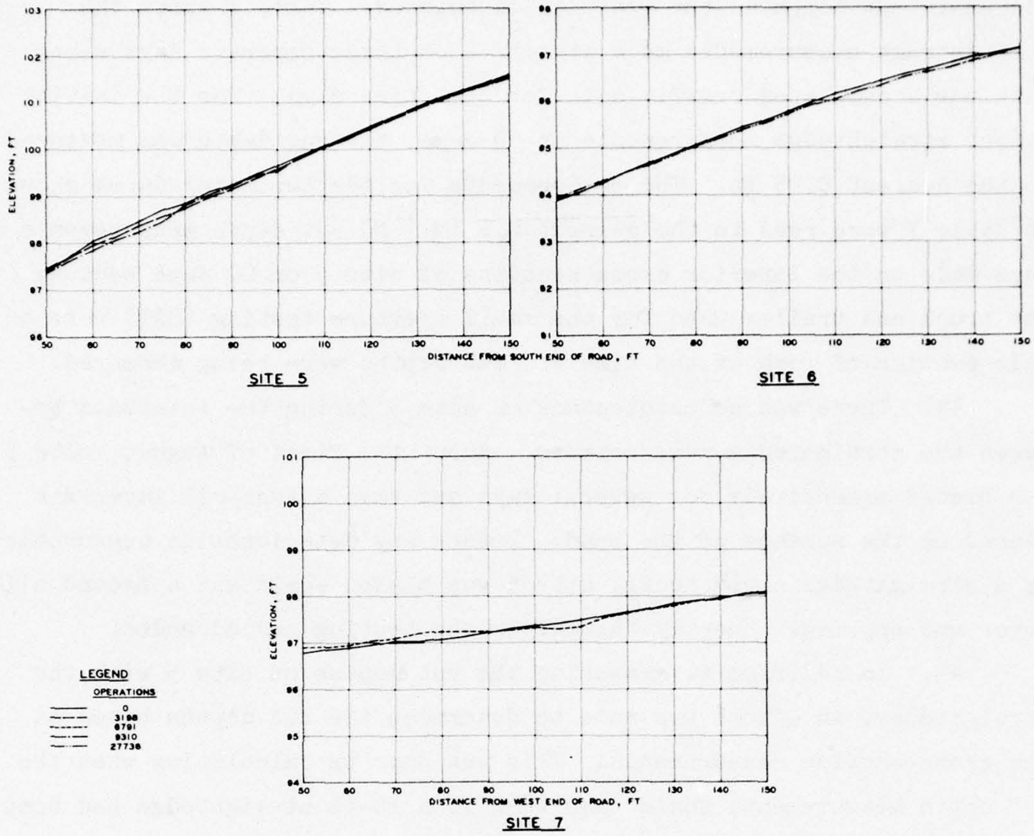


Figure 17. Typical profile measurements on test sites 5 through 7

Permanent deformation

43. Another method used to measure the road surface roughness or deformation was a standard 10-ft straightedge shown in Photo 22. The straightedge was placed transversely across the road and surface deviations from the straightedge were measured. Although the straightedge was primarily used to measure the rut depth at various locations, it could also be used to measure other surface geometry. The straightedge was used on all seven sites throughout the testing period. However, the only measurable ruts occurred on sites 5 and 6. Since site 6 was graded almost daily, it was virtually impossible to measure any appreciable change in rut depth. In contrast to site 6, site 5 had very little maintenance making it possible to detect a significant

change in rut depth as the traffic accumulated. Table 7 shows the straightedge measurements made at site 5 on three separate days along with the accumulated traffic data for the three days. For the initial set of straightedge measurements on 20 June, the rut depth was measured to the nearest 0.25 in. The measurements for the two later dates shown in Table 7 were read to the nearest 0.1 in. No rut depth measurements were made on the interior cross sections of site 5 on 20 June because the truck and trailer used for the small aperture testing (SAT) were on this section of road at the time the rut depths were being measured.

44. There was no maintenance on site 5 during the intervals between the straightedge measurements. About the first of August, site 5 was bladed extensively for several days and then a dust-oil layer was placed on the surface of the road. Before any deterioration measurable by a straightedge could occur, site 5 was bladed again and a second oil layer was applied. Shortly thereafter the testing period ended.

45. In addition to measuring the rut depths on site 5 with the straightedge, an effort was made to determine the rut depths based on the cross-section measurements. This was done by calculating what the rut depth measurements would have been if a 10-ft straightedge had been placed on the cross-section points. The results from this procedure are shown in Table 8. While the rut depths as measured by the cross sections should not be as accurate as the straightedge measurements, they should be reasonably accurate, especially for the deeper ruts. There were only four points on site 5 where the cross-section measurements and the straightedge measurements were made at about the same time. For these four points, the cross sections made on 19 June showed an average rut depth of 0.92 in. while the straightedge measurements conducted on 20 June showed an average rut depth of 0.94 in.

Structural Properties

Small aperture testing (SAT)

46. In addition to the surface roughness measurements, the structural properties of the soil were also tested to determine the road

deterioration at all seven sites at various intervals. Most of the testing was accomplished by a SAT procedure that is described in detail by Hall and Elsea.[1] The SAT equipment consists of a small trailer-mounted drill rig (shown in Photo 23) which has a standard 6-in.-diam core drill. Hydraulic lifting jacks were installed in the trailer to provide a stable working platform. An important feature of the drill rig is the sliding-base arrangement which allows the coring of the pavement, the removal of the drill assembly from the hole to perform the desired tests, and the automatic realignment of the drill assembly for further advancement of the hole. A thin-walled diamond-core barrel was used for coring the asphalt pavement as shown in Photo 24. An auger was used for advancing the hole into the base or subgrade as shown in Photo 25.

California Bearing Ratio (CBR) tests

47. An integral part of the SAT procedure is a modified CBR test that is conducted in the 6-in.-diam hole made by the drill rig. Photo 26 shows the CBR test setup for the SAT procedure. This modified CBR test differs from the conventional test pit CBR in that no surcharge weights are placed around the CBR piston to replace the overburden material that is removed when the test pit is excavated. Since the SAT CBR's are measured with the natural overburden on the pavement layers, no surcharge weights are necessary. A series of tests comparing SAT CBR values with the conventional test pit CBR values at identical locations have shown reasonably good agreement.[1] SAT CBR values tend to be slightly higher than conventional values and must be slightly modified to agree with conventional CBR test values.

48. For the asphalt surfaced test sites such as sites 1 and 2, the modified CBR test was run at three different depths. These were the top of the base immediately below the pavement, the top of the subgrade, and 12 in. below the surface of the subgrade. For the aggregate surfaced sites such as site 5, the CBR was measured on the road surface, on the top of the subgrade, and 12 in. into the subgrade. For the unsurfaced test sites such as sites 6 and 7, the CBR test was run on the road surface and 12 in. below the road surface. For each SAT series, two adjacent holes were drilled and the CBR was measured at each depth

in each hole. If the two CBR's differed greatly at any depth, a third hole was drilled and a third set of CBR's were taken. The final CBR value was obtained by averaging the CBR's for each depth.

49. Only one series of CBR tests was run at site 7 on Herring Creek Road. Two to four series of tests were conducted at the other six sites during the testing period. At each site the initial set of CBR tests was conducted in one of the loaded log truck wheel paths at station 0+25. Each succeeding series of CBR tests was moved up in the same wheel path about 50 ft from the previous series. The testing dates and CBR values are listed for all seven sites in Table 9. Also included in this table are the cumulative traffic data for the sites on the date of testing.

Moisture and density

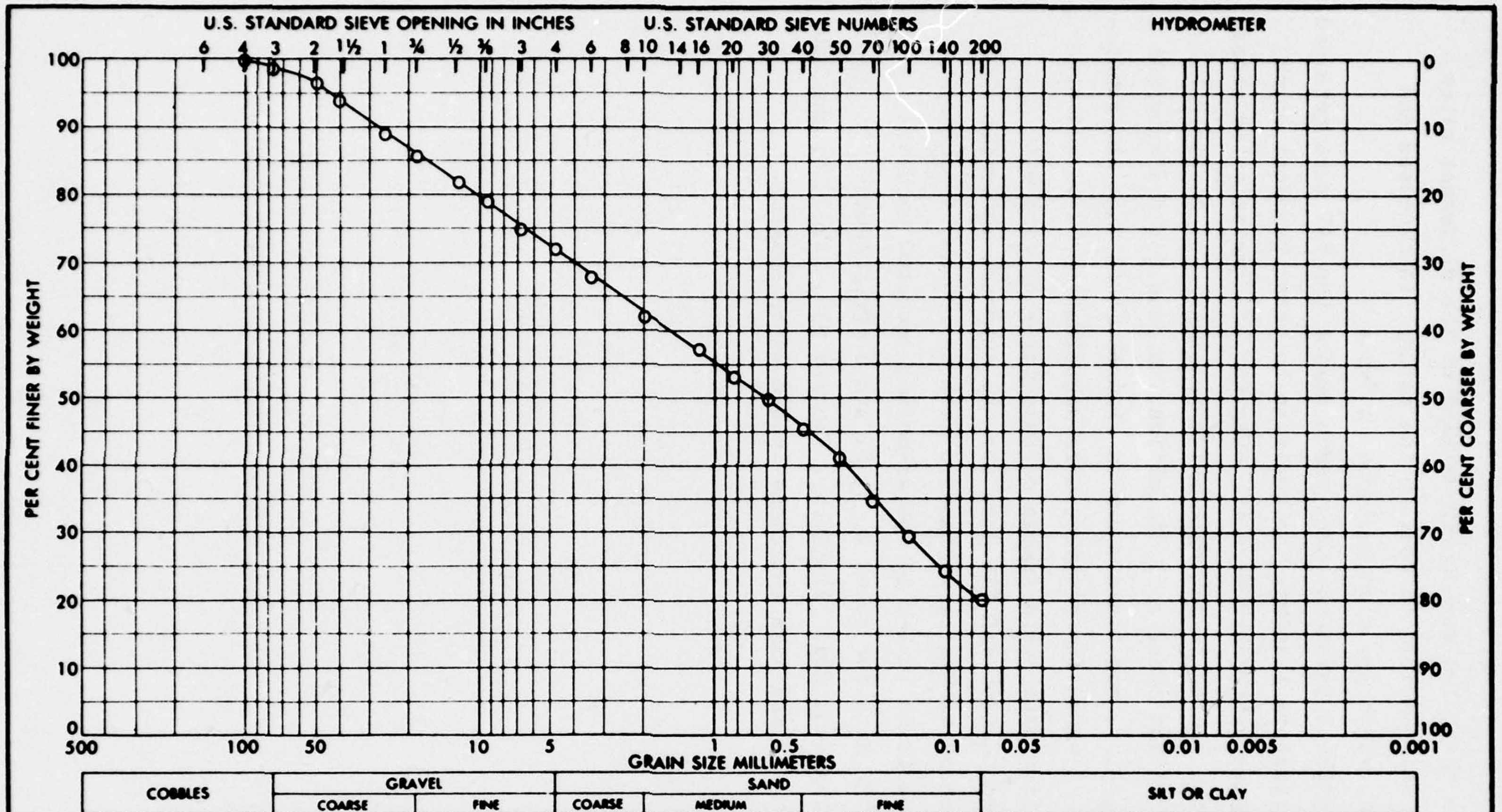
50. In addition to measuring the CBR, the SAT procedure included the determination of water content and dry density of the base and subgrade. Soil samples were taken from the drill holes at the same depth at which the CBR tests were conducted. These samples were weighed and then oven-dried to determine the water contents which are shown in Table 9. The dry density of the base and subgrade was determined using two types of nuclear devices. These nuclear gages actually measured the wet density of the soil; but from this measurement and the water content values, the dry density could be calculated.

51. The device primarily used with the SAT was a special nuclear density apparatus developed for WES by a commercial source. This device is shown in Photos 27 and 28. When using the apparatus a nuclear source (cesium) is placed in one core hole and a detector tube is placed in a second hole at the same depth. This apparatus measures the density of a 2-in.-thick layer and may be used for many different depths. The procedure requires the two CBR holes to be spaced from 11 to 14 in. apart.

52. The other type of nuclear device was a Troxler Model No. 2401. This gage, shown in Photo 29, was used for determining the dry density at the road surface on aggregate surfaced and unsurfaced test sites. The calculated dry densities at different depths for all seven sites are shown in Table 9.

53. While the holes were being drilled at the different sites for the SAT, it was possible to measure the asphalt thicknesses and base thicknesses, which are also included in Table 9.

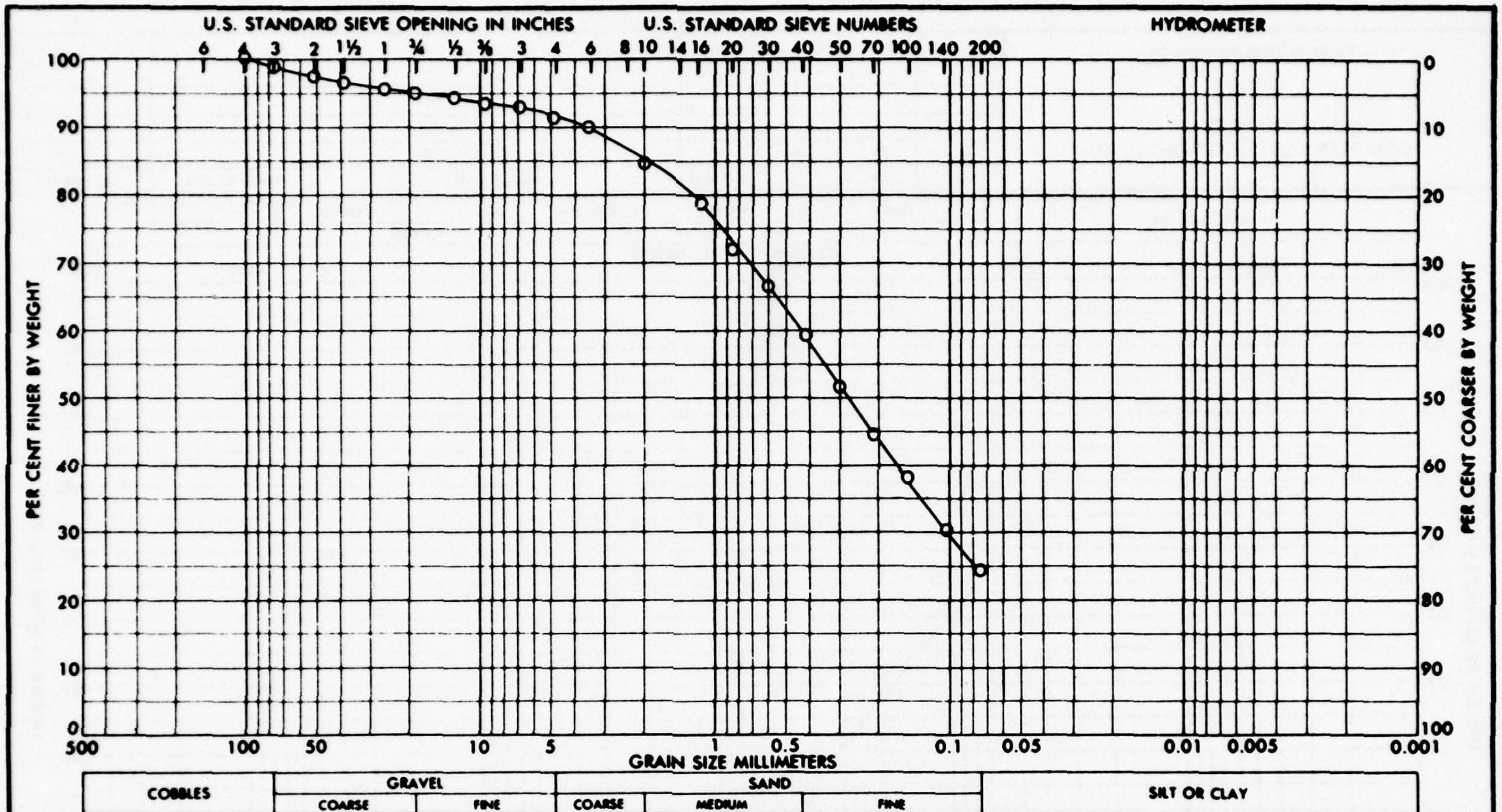
54. The asphalt pavement cores taken during the SAT were retained for possible laboratory testing. In addition to these pavement cores, 500-lb soil samples were taken from the subgrade of some selected sites and shipped to the WES soils laboratory for testing. The particle size distribution curve and other soil classification data for the subgrade soil of sites 2, 4, 5, and 6 are shown in Figures 18 through 21, respectively. Figure 22 shows the particle size distribution curve and other soil classification data for a sample of base material from site 3. The laboratory compaction and CBR data for the subgrade materials were determined according to Military Standard Methods 100 and 101, respectively.[2] For specimens tested in the as-molded unsoaked condition, the compaction and CBR data for sites 2, 4, 5, and 6 are presented in Figures 23a, 24a, 25a, and 26a. Similarly, Figures 23b, 24b, 25b, and 26b include the data for the same specimens tested after soaking.



SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
SITE 2		GRAVELLY, SILTY SAND (SM)		NP		
		REDDISH BROWN				
		GS = 2.69				

TEST ROAD AT STANISLAUS
SONORA
SITE 2
6 AUGUST 1974

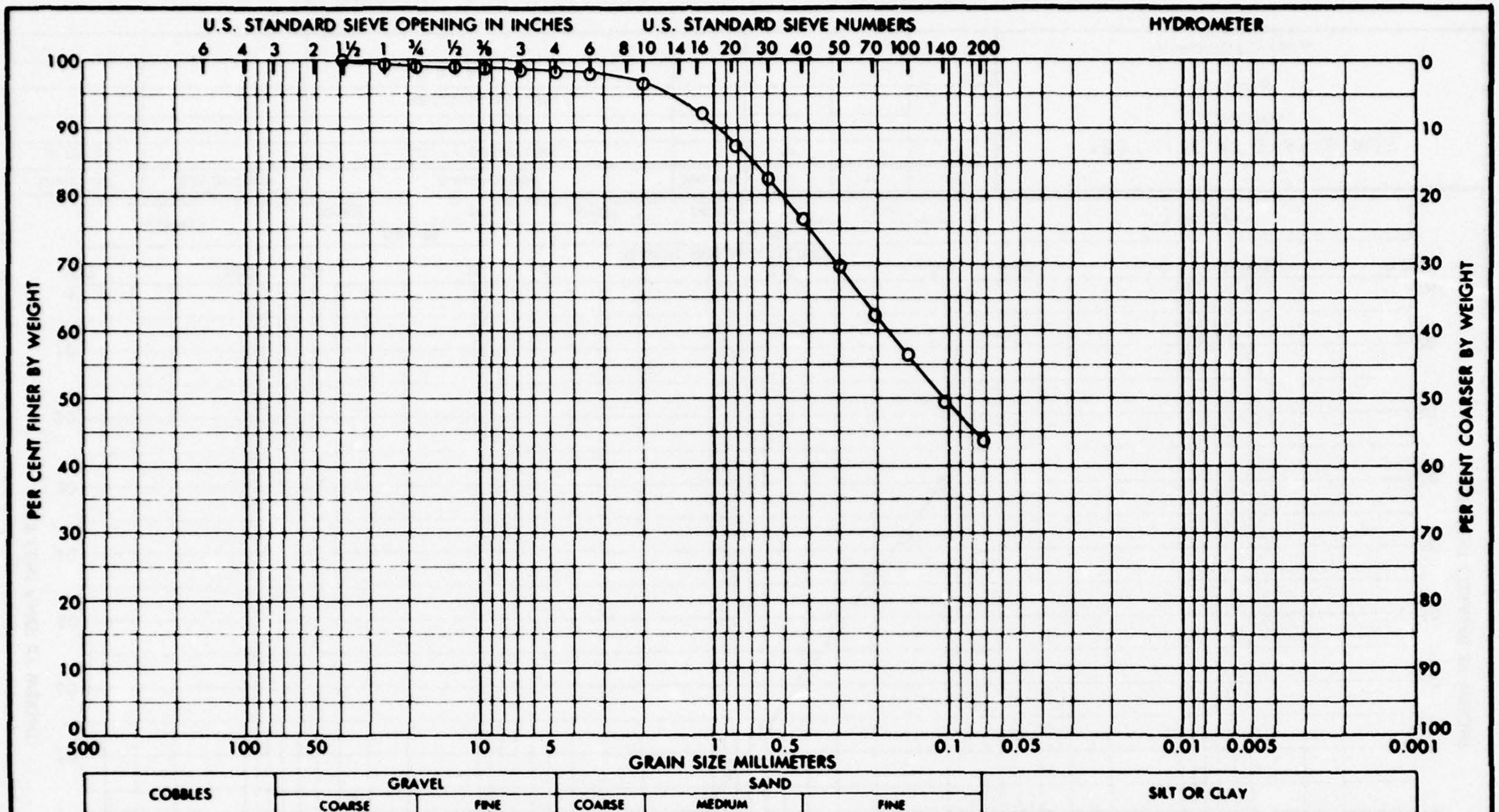
Figure 18. Classification data for subgrade from test site 2



SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
SITE 4		SILTY SAND (SM)		NP		
		WITH GRAVEL				
		REDDISH BROWN				
		GS = 2.80				

TEST SITE AT STANISLAUS
SONORA
SITE 4
6 AUGUST 1974

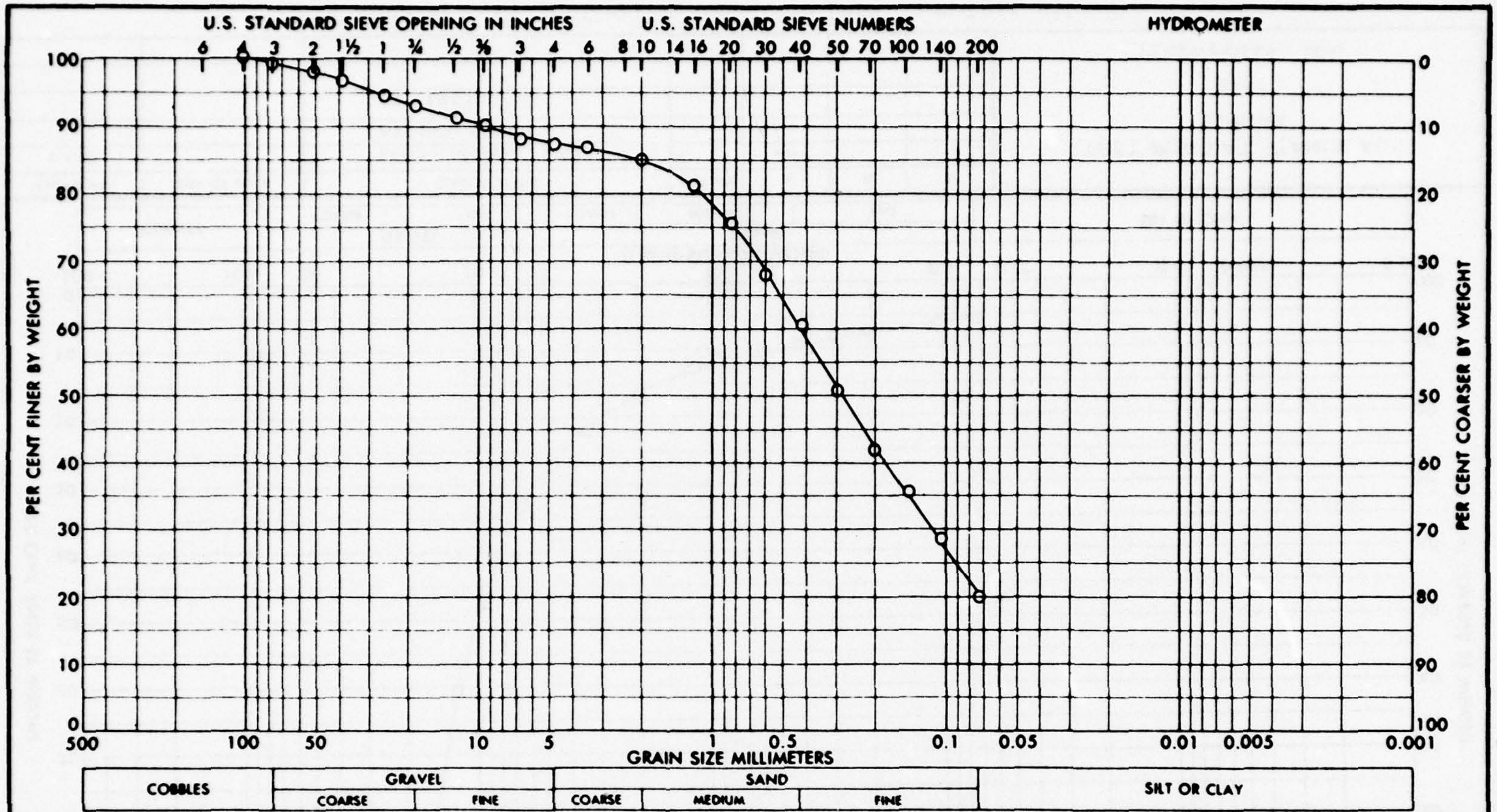
Figure 19. Classification data for subgrade from test site 4



SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
SITE 5		SILTY SAND (SM)		50	38	12
		REDDISH BROWN				
		GS = 2.70				

TEST ROAD AT STANISLAUS
SONORA
SITE 5
13 SEPTEMBER 1974

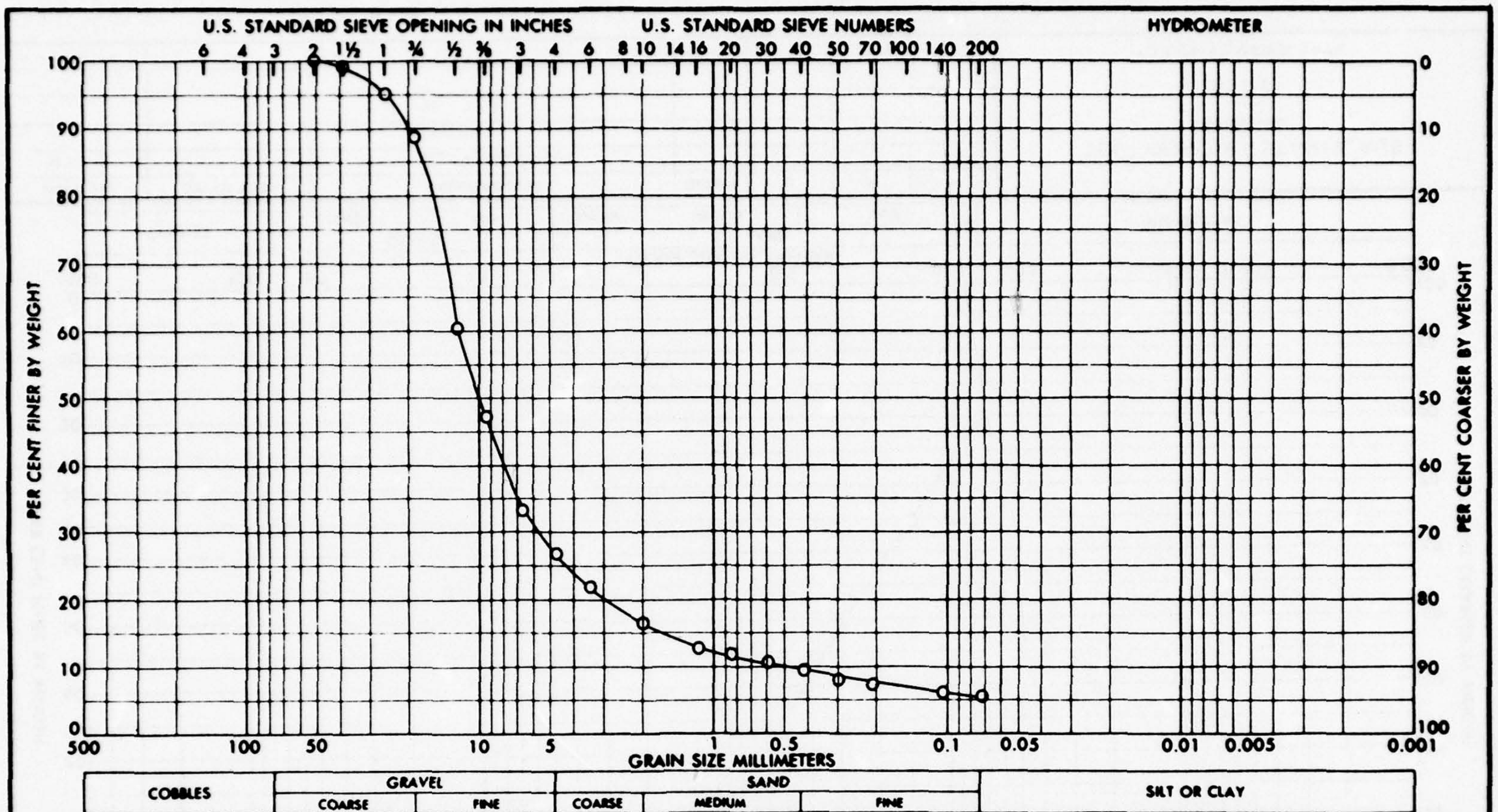
Figure 20. Classification data for subgrade from test site 5



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
SITE 6		SILTY SAND (SM)				
		BROWN				
		GS = 2.69				

TEST ROAD AT STANISLAUS
SONORA
SITE 6
13 SEPTEMBER 1974

Figure 21. Classification data for subgrade from test site 6



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
BASE		SANDY GRAVEL (GP-GM)		NP		
		REDDISH BROWN				
		GS = 2.65 (EST ∠)				

TEST ROAD AT STANISLAUS
SONORA
BASE
13 SEPTEMBER 1974

Figure 22. Classification data for base from test site 3

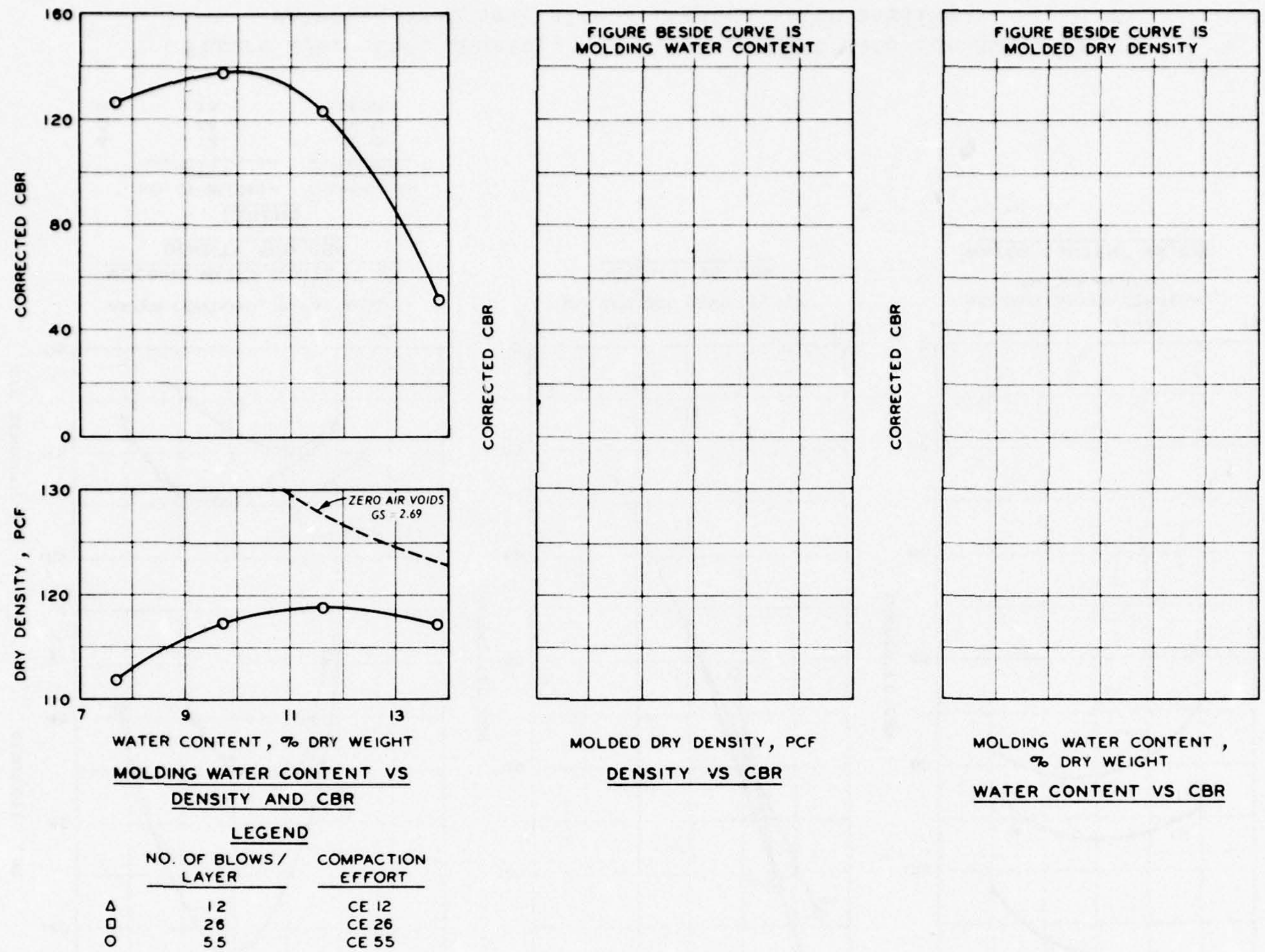


Figure 23a. CBR, density, and water content data for subgrade material from test site 2 (tested as molded)

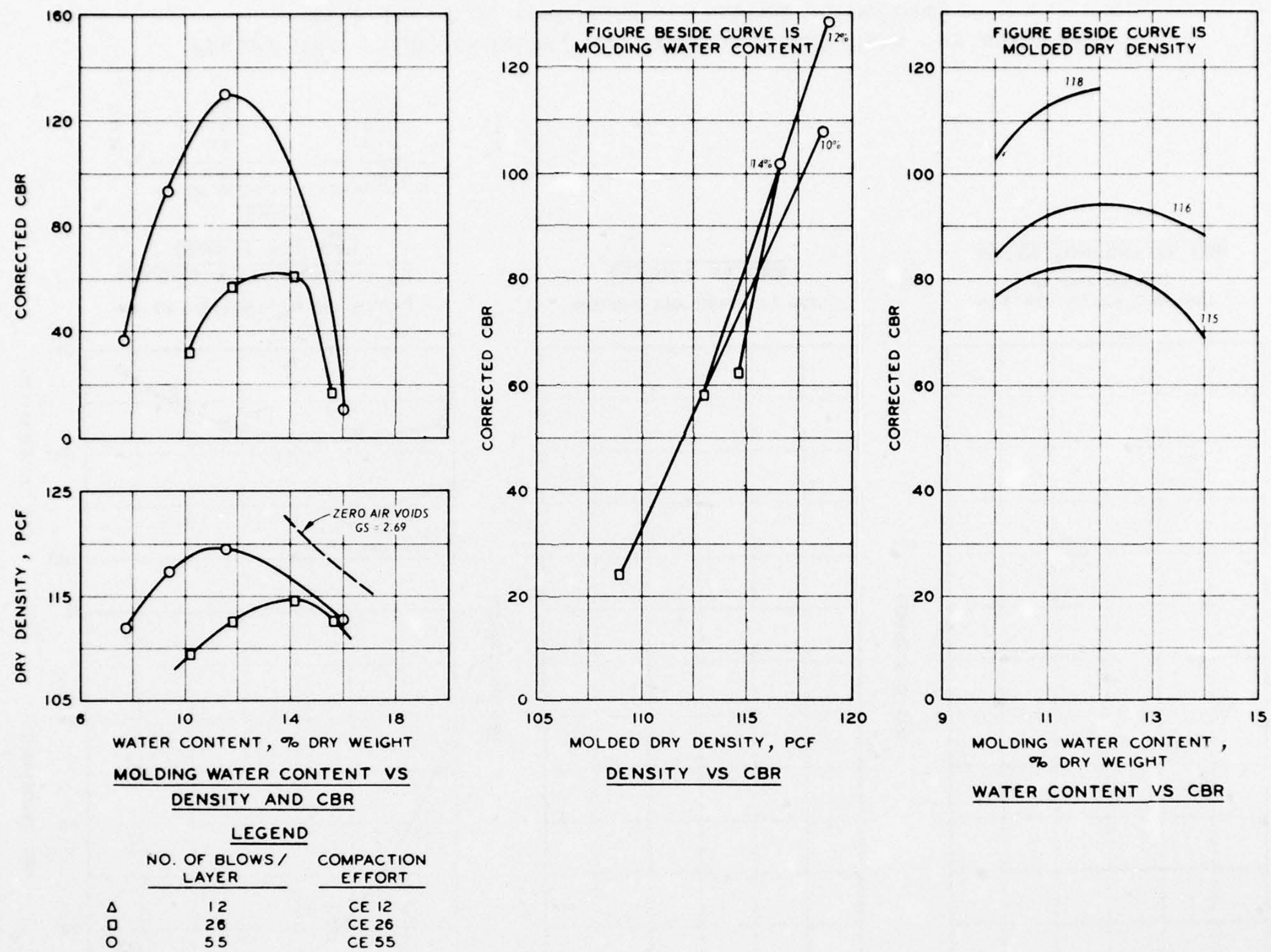


Figure 23b. CBR, density, and water content data for subgrade material from test site 2 (tested after soaking)

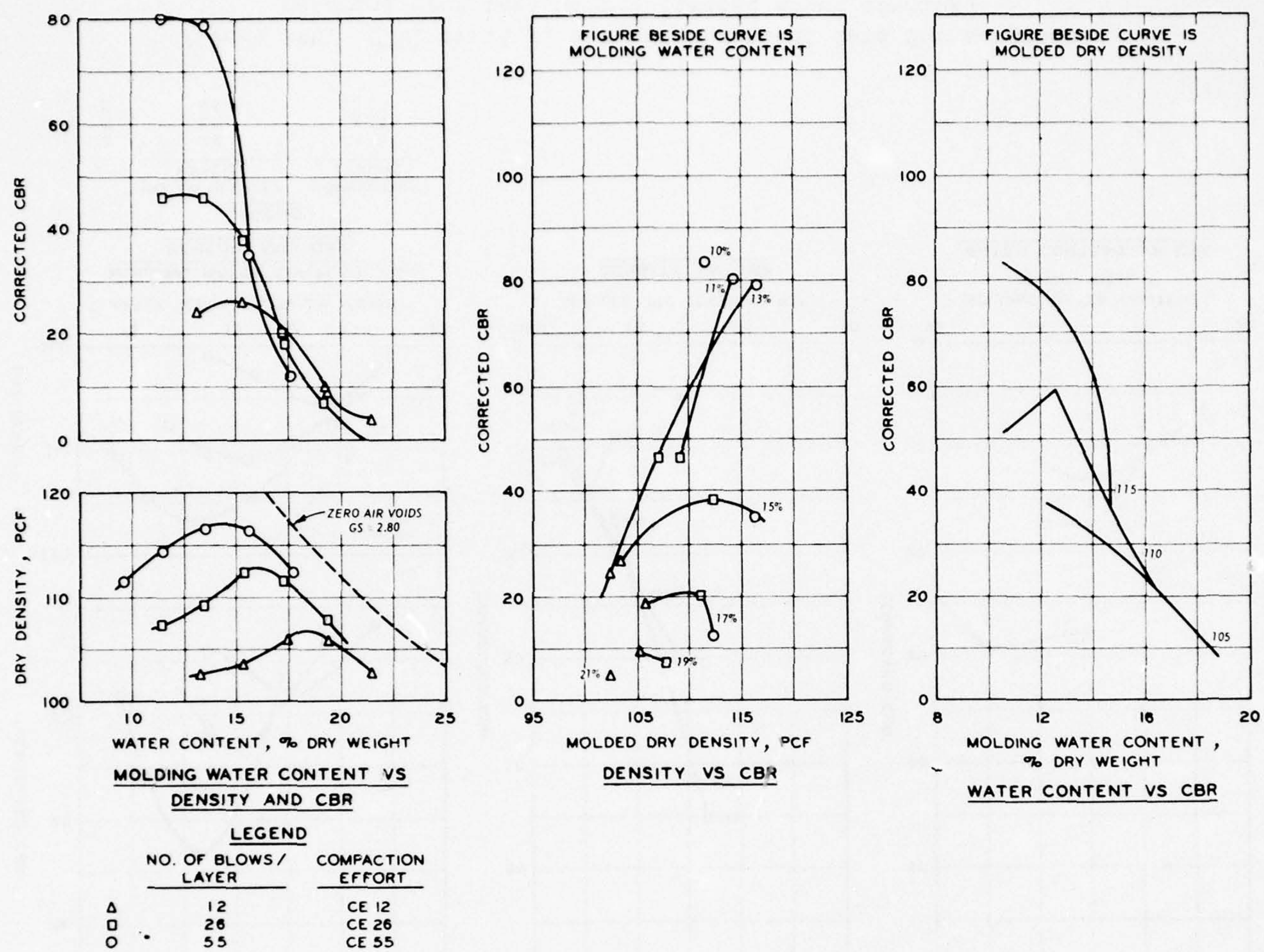


Figure 24a. CBR, density, and water content data for subgrade material from test site 4 (tested as molded)

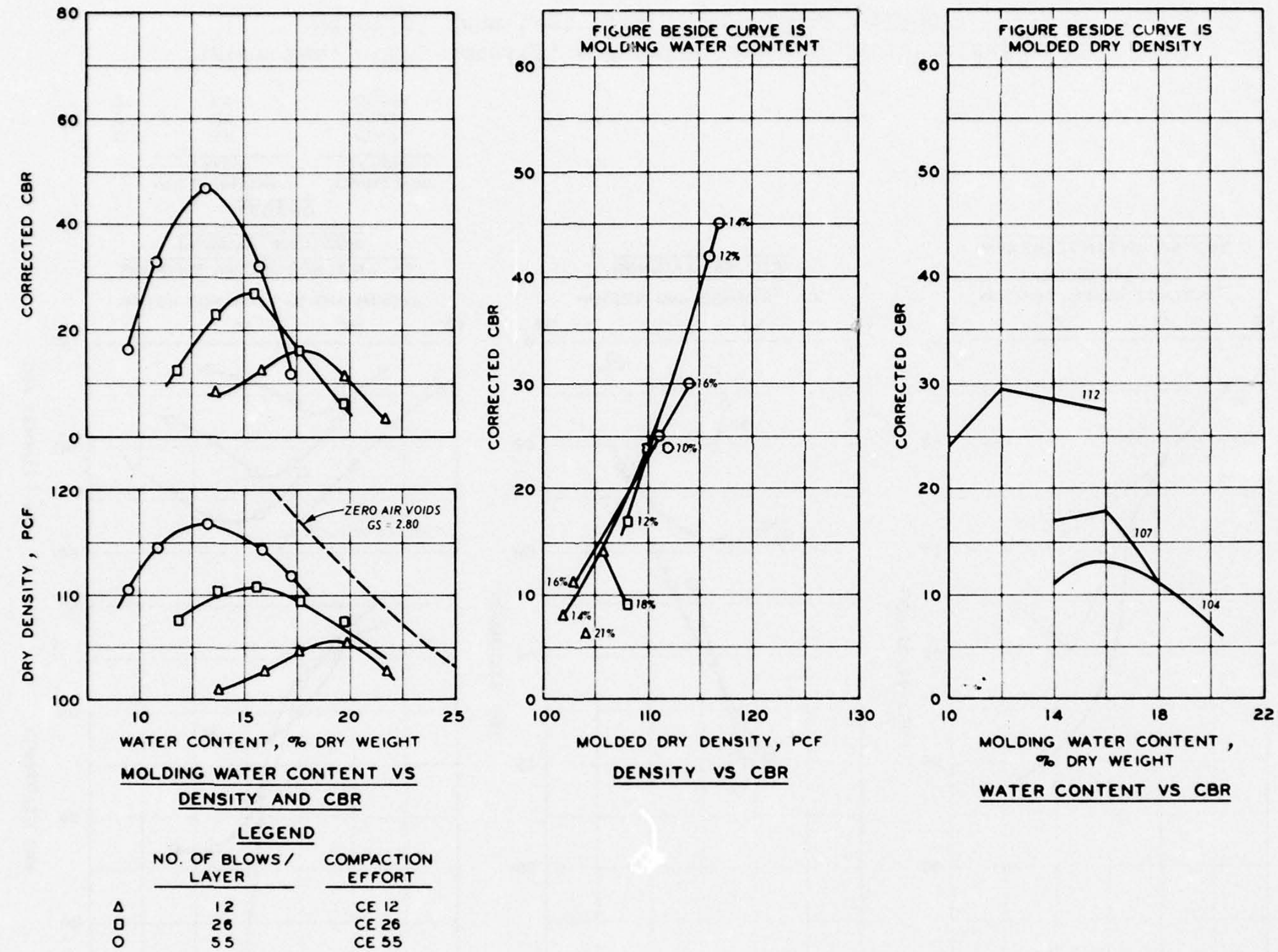


Figure 24b. CBR, density, and water content data for subgrade material from test site 4 (tested after soaking)

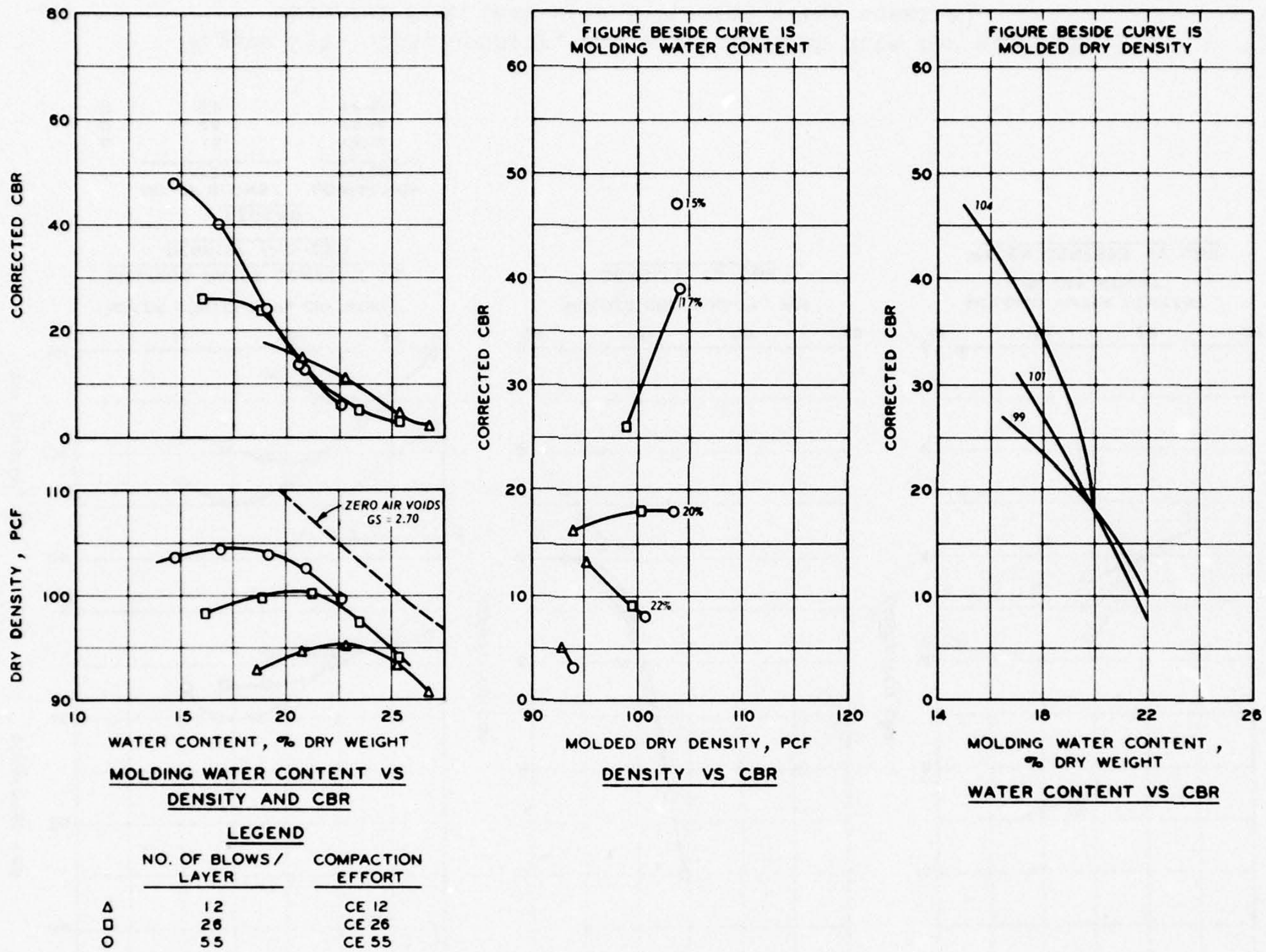


Figure 25a. CBR, density, and water content data for subgrade material from test site 5 (tested as molded)

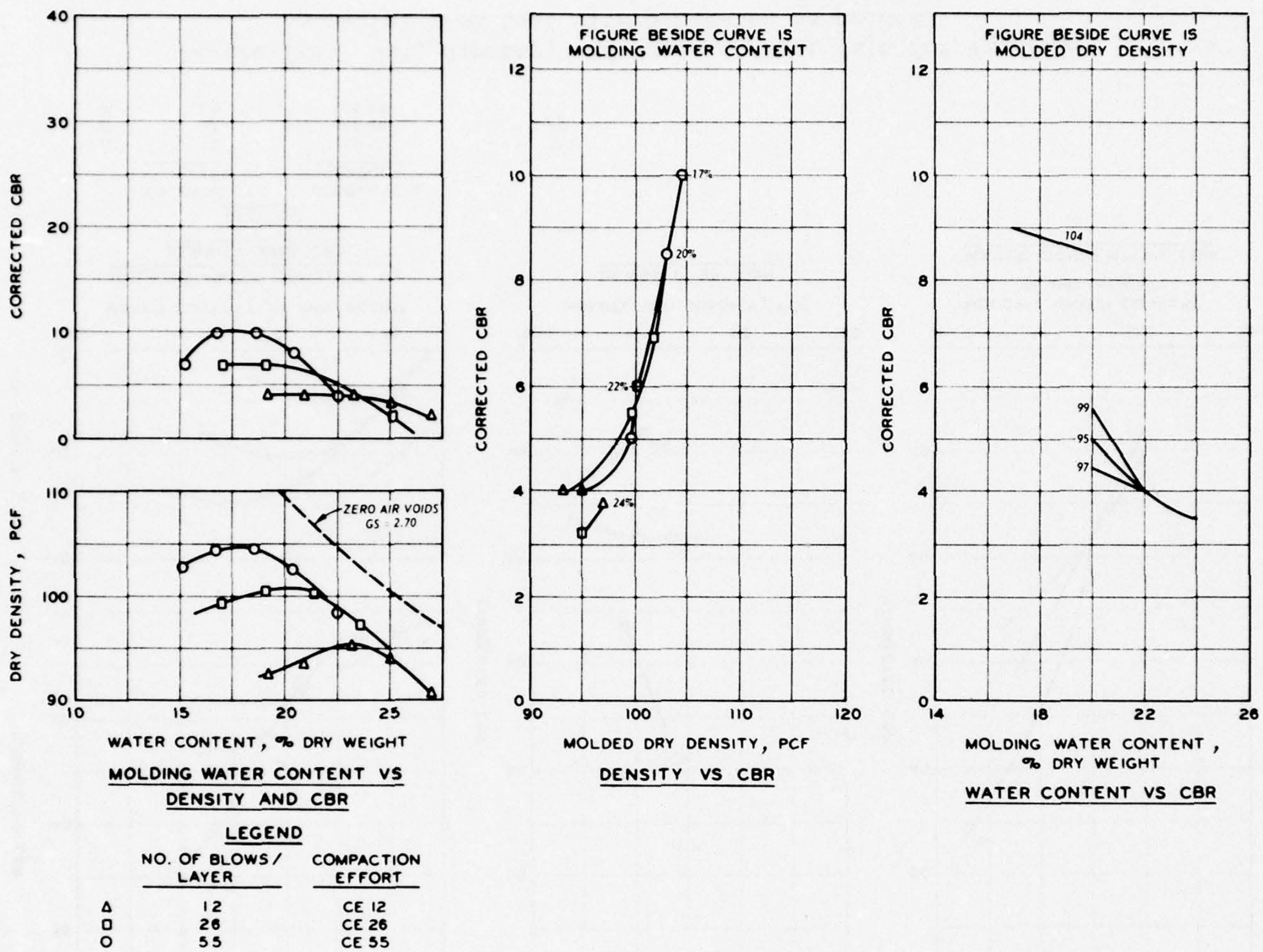


Figure 25b. CBR, density, and water content data for subgrade material from test site 5 (tested after soaking)

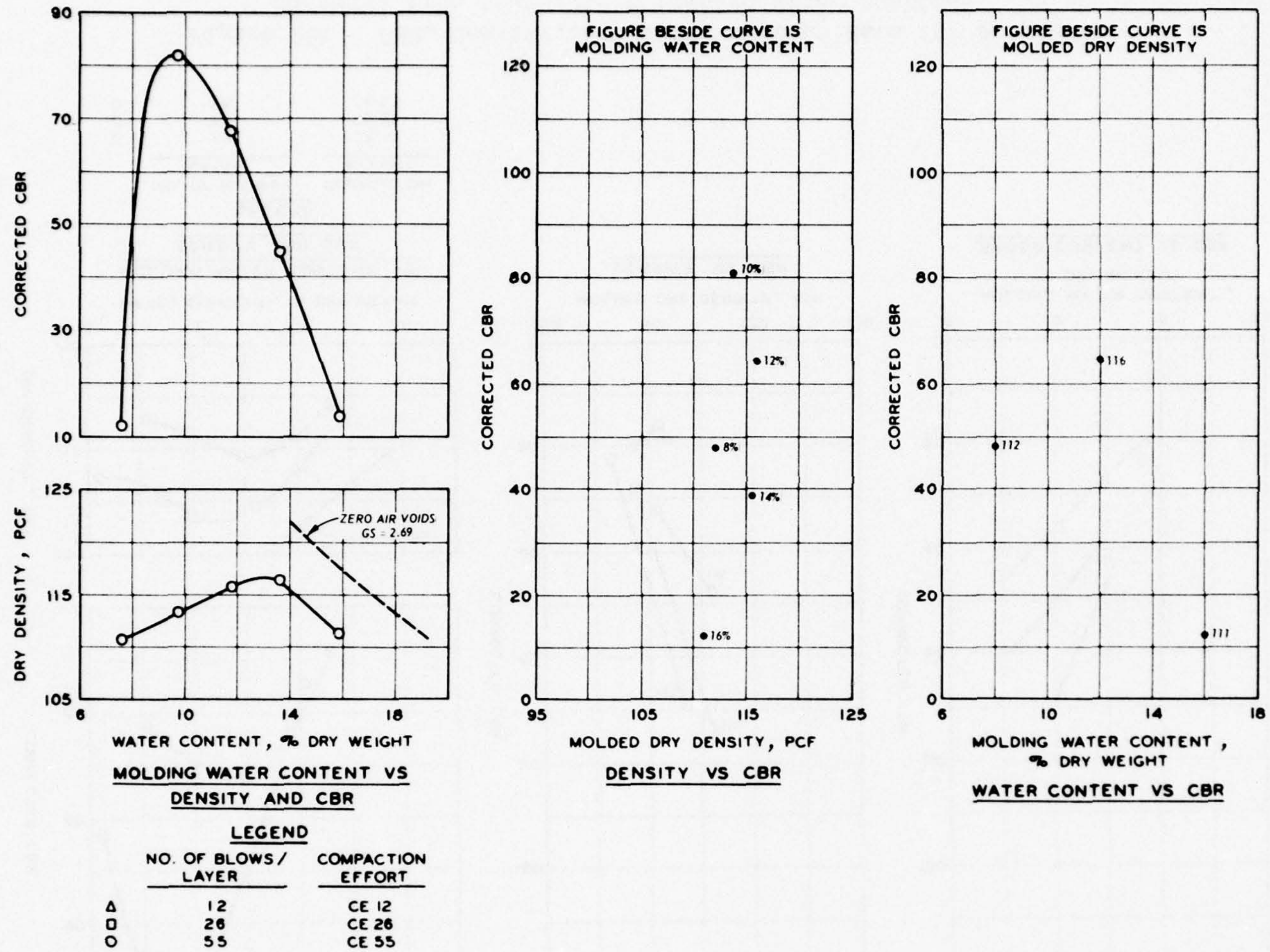


Figure 26a. CBR, density, and water content data for subgrade material from test site 6 (tested as molded)

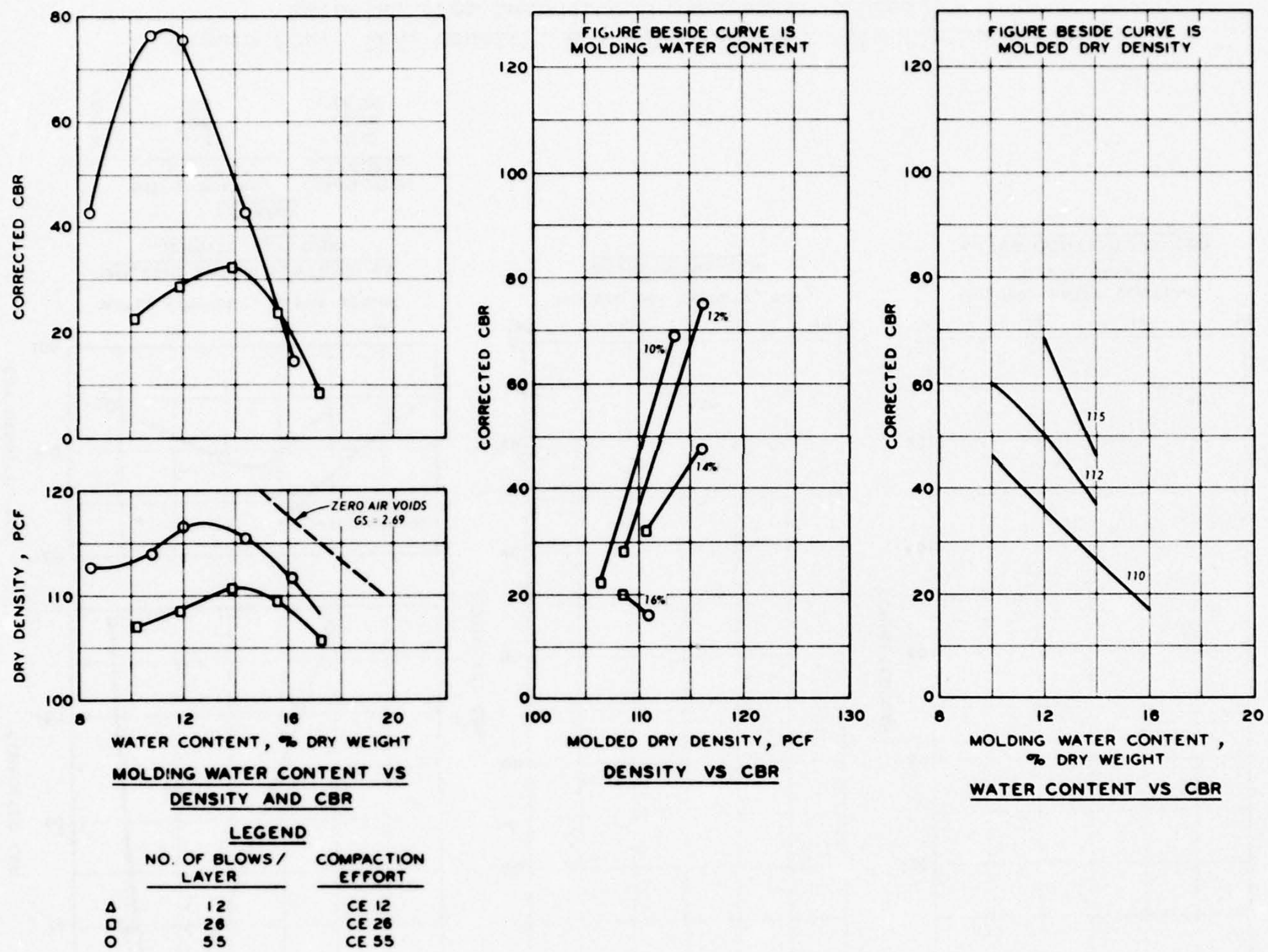


Figure 26b. CBR, density, and water content data for subgrade material from test site 6 (tested after soaking)

PART III: RESULTS OF TESTS

Site 1

55. Site 1, located on Cottonwood Road, was one of the two sites having an asphalt surface at the beginning of the testing period. Figure 1 shows the general location of site 1 with respect to the other five sites in the area, while Figure 2 shows the plan and profile views of site 1.

56. The pavement on site 1 did not experience a general failure during the testing, but there were two areas on site 1 where small localized failures occurred. These failures were caused by the loss of bond between the surface layer of asphaltic concrete and the underlying base layer. Due to the slippage failures and other similar failures, a 1.2-mile section of Cottonwood Road which included site 1 was given a 2-in. asphalt overlay on 28 June. After the overlay was placed, there were no other failures on site 1 or any other location covered by the overlay.

57. A summary of the traffic data collected on site 1 showing the weekly accumulative vehicle operations in the westbound lane is presented in Table 1. As with the other three test sites on Cottonwood Road, the westbound lane was the traffic lane that the loaded log trucks traveled while the returning empty log trucks traveled in the eastbound lane. By the end of the testing period there was a total of 29,661 loaded log trucks having passed over site 1. In addition to the log trucks there were 5,490 vehicles in the medium truck category and 17,951 other vehicles totaling 53,102 vehicles for the testing period.

58. The cross-section data collected on site 1 at stations 0+25, 0+75, 1+25, and 1+75 are presented graphically in Figure 9. Cross sections were taken at five different levels of traffic operations at each of the four stations. These figures indicate the change in surface elevation after the 2-in. asphalt overlay was added. As shown by these figures, there was little change in roughness or deformation between operation levels. Since there was minimal rutting, no straightedge

measurements were recorded for site 1.

59. The profile data were collected along two 200-ft lines as shown in the plan view of Figure 2. Profile line No. 1 was in the outside wheel path of the eastbound lane, while profile line No. 2 was in the outside wheel path of the westbound lane. Profiles taken along the interior 100 ft of profile line No. 2 are illustrated in Figure 16. These profiles show that the westbound lane of site 1 had a downhill slope of about 6.5 percent. As indicated by Figure 16, the profile of site 1 remained relatively smooth during the entire testing period.

60. The results from the SAT performed on site 1 are shown in Table 9. This testing was performed on two dates before the asphalt overlay was placed. The accumulative traffic operations in the westbound lane for the two testing dates are included in Table 9. The traffic for 28 June, which was the date of the asphalt overlay, is also shown. No SAT was performed on site 1 at the conclusion of the testing because the pavement showed no sign of distress. The asphalt thicknesses listed in Table 9 were determined by measuring the asphalt cores that were removed during the SAT procedure. For site 1 the asphaltic concrete layer was 6 in. thick before the overlay. The base course thickness of 3 in. was measured when the core hole was advanced into the subgrade in order to perform the CBR tests. The pavement structural layer thicknesses and the CBR values from the initial SAT are illustrated in Figure 2. As shown in Table 9, the CBR's on the top of the base for the two testing dates were 61 and 63, respectively. The CBR's on the top of the subgrade were 13 and 41, respectively, while at 1 ft into the subgrade the CBR's were 13 and 26. Table 9 also lists the water content and dry density of the soil at each location at which the CBR test was performed. No soil samples were taken from the subgrade of site 1 for laboratory testing.

Site 2

61. Site 2 also had an asphalt surface at the beginning of the testing period. The location of site 2 on Cottonwood Road is shown in

Figure 1; the plan and profile views of site 2 are shown in Figure 3. This site was located on the side of a mountain with the eastbound lane lying primarily on a cut section, and the westbound lane resting on a rock fill. A notable feature of site 2 was a pullout lane adjacent to the westbound lane for loaded log trucks to park and readjust the chains restraining the logs. Loaded log trucks using the pullout lane often did not pass over the westbound lane in site 2. To determine the percentage of the log trucks that did not travel on the westbound lane, many traffic samples were taken at site 2. The results from these traffic samples were used to calculate the number of loaded log trucks that actually used the westbound lane.

62. The weekly accumulative vehicle operations in the westbound lane of site 2 are given in Table 2. By the end of the testing period 23,599 loaded log trucks, 5,490 medium trucks, and 17,951 other vehicles had used the lane for a cumulative total of 47,040 vehicle operations.

63. Cross-section data from site 2 taken at four different stations at four operational levels are depicted in Figure 10. The cross sections of site 2, similar to those of site 1, remained relatively smooth throughout the testing period. No straightedge measurements were recorded at site 2 due to the lack of significant rutting.

64. The two profiles obtained on the interior section of the loaded log truck profile line are illustrated in Figure 16. These profiles indicate that the westbound lane of site 2 had a slope of about 7.5 percent. In addition, these profiles show that there was little deformation during the test period.

65. Table 9 lists the results from the SAT on site 2. The dates of testing and the accompanying traffic levels are also included. Due to the lack of pavement deterioration, SAT was not done at the end of the test period. The asphalt and base thicknesses of 7 in. and 3 in., respectively, as well as the initial CBR's of the base and subgrade are shown in Figure 3. A CBR of 15 was measured on the top of the base course in May, while a CBR of 68 was measured in June. At the top of the subgrade the CBR's were 17 and 26, respectively, for these two dates while 12 in. into the subgrade CBR values of 39 and 82, respectively,

were measured. The water content and dry density of the soil for each CBR location are also given in Table 9.

66. A 500-lb disturbed soil sample of the subgrade from site 2 was returned to WES for laboratory testing. The gradation curve of the site 2 subgrade is presented in Figure 18. This soil was nonplastic and classified as a gravelly, silty sand (SM) according to the Unified Soil Classification System (USCS).[3] Figures 23a and 23b present the laboratory compaction and CBR data for the site 2 subgrade material. These data were determined according to Standard Military Methods 100 and 101.[2] The CBR data in Figure 23a are for specimens tested in the as-molded unsoaked condition. The data in Figure 23b are for specimens tested after soaking.

Site 3

67. Test site 3, located on a rock and earth fill section, was unsurfaced at the beginning of the field tests. Figure 1 shows the general location of site 3, while Figure 4 shows the plan and profile views of site 3. The contractor began placing an aggregate base course on site 3 a few weeks after the testing period began. After the base course was in place, 4 in. of asphaltic concrete were placed on this site in two layers. The surface layer of asphalt was placed about 7 August.

68. Table 1 gives the accumulative vehicle operations by week in the westbound lane of site 3. On 9 August, which was the end of the work week, the asphalt paving was completed; 19,109 loaded log trucks, 4,219 medium trucks, and 11,929 other vehicles had traveled on this site. When the testing period was completed there had been a total of 29,661 loaded log trucks, 5,490 medium trucks, and 17,951 other vehicles for a cumulative total of 53,102 operations.

69. The cross-section data collected on site 3 are presented in Figure 11, while data representative of the profile along the loaded log truck lane are illustrated in Figure 16. Only two sets of profile and cross-section data were taken during the testing period; the initial

data were measured when site 3 was unsurfaced while the final set was taken after site 3 was paved. No other profile and cross-section data were measured because the profile and cross-section elevations were continually changing due to the construction activity involved in placing the aggregate base. The figures presenting the profile and cross-section data show that the increase in elevation due to the addition of the base course and asphaltic concrete was between 13 and 14 in. The profile data also indicate that the westbound lane of site 3 had a slope of about 4.0 percent downhill when it was unsurfaced and a slope of 3.5 percent after paving. Since no significant rutting occurred on site 3, no straightedge measurements were made.

70. The SAT data from site 3 are listed in Table 9 along with the accumulative traffic operations for the three dates of testing. During the initial series of testing there was no base on the site. The CBR on the road surface was 80, while at 12 in. below the surface the CBR exceeded 100. Although about 6 in. of base existed on site 3 on the second date of testing, no CBR tests were run because the base was not fully compacted. A CBR of 95 was measured on the top of subgrade at this time. The presence of large rocks immediately below the subgrade surface at this testing location made it impractical to drill a hole 12 in. into the subgrade to measure the CBR. When the final SAT series on site 3 was conducted, 4 in. of asphalt had been placed on a 9.5-in. base course. On this date a CBR of 40 was measured on the top of the base, while the CBR on the top of the subgrade was 82, and the CBR 12 in. below the subgrade surface exceeded 100.

71. Table 9 lists the water content and dry density of the soil at each CBR location where these measurements could be made. The dry density could not be determined at the 12-in. level in the subgrade for the first two testing dates because of the difficulty involved in obtaining the pair of smooth-sided holes required for the nuclear testing device. When drilling the holes for the CBR tests, the auger dislodged large rocks in the subgrade making the edges of the holes very ragged. This problem was encountered only on site 3. For the final testing in September, no dry density data could be measured due to a faulty nuclear

density gage. No soil samples were taken from the site 3 subgrade for laboratory testing.

Site 4

72. This site was the easternmost test site on Cottonwood Road. At the outset of the field tests site 4 was unpaved, but the aggregate base was already in place. The subgrade surface of site 4 approximated the natural contour of this area with a few slight cut and fill sections. The general location of site 4 is shown in Figure 1, while the plan and profile views of site 4 are shown in Figure 5.

73. The weekly accumulative vehicle operations in the westbound lane of site 4 are presented in Table 3. Since there were several feeder roads intersecting Cottonwood Road between site 4 and sites 1 through 3, this site did not experience as much log-hauling traffic as the other three sites on Cottonwood Road. The asphalt surfacing on site 4 was completed about 1 August. By 2 August, 13,757 loaded log trucks had passed over site 4. In addition to the log trucks, 2,868 medium trucks and 7,330 other vehicles had passed over the site for a total of 23,955 vehicles. The traffic for the entire testing period included 22,714 loaded log trucks, 3,975 medium trucks, and 12,083 other vehicles.

74. Cross-section data from site 4 taken at three different traffic levels are depicted in Figure 12. The first two cross sections in this figure were obtained before the asphalt placement while the final cross section was made after the asphalt surfacing.

75. The interior 100 ft of the profile line in the westbound lane of site 4 initially had a slope downhill of about 5.0 percent which changed to a slope of about 4.5 percent after paving. The cross-section and profile data show little apparent change in the roughness of the road during the unpaved state. Straightedge measurements were not made since little rutting occurred.

76. The SAT data gathered on site 4 are presented in Table 9. Included in this table are the testing dates and accompanying traffic

levels. For the first two SAT series the CBR on the top of the base was determined to be 95 and 100 plus, respectively. CBR values of 19 and 24, respectively, were measured on top of the subgrade, while at 12 in. into the subgrade the CBR was first 32, then 22. After site 4 was paved, a CBR of 110 was measured on top of the base; a CBR of 32 was measured on top of the subgrade; and a CBR of 10 was measured 12 in. below the subgrade surface. The soil water content and dry density for each CBR test location in the first two series of testing are also listed in Table 9. For the September SAT only the water content of the soil is listed since the gage used to measure the dry density was inoperative.

77. A disturbed soil sample of about 500 lb was collected from the subgrade of site 4 and returned for laboratory testing. Figure 19 depicts the gradation curve of this sample. The soil was nonplastic and classified as SM under the USCS.[3] The laboratory compaction and CBR data for the site 4 subgrade material determined according to Standard Military Methods 100 and 101[2] are presented in Figures 24a and 24b. Figure 24a represents data for as-molded unsoaked soil specimens. The data in Figure 24b are for specimens tested after soaking.

Site 5

78. Site 5 was located on 3N01 North, one of the secondary roads intersecting Cottonwood Road. This was a single-lane road with an aggregate surface at the start of the field testing. Figure 1 shows the general location of site 5 while Figure 6 shows the plan and profile views of site 5.

79. The aggregate surface of 3N01 North had some slight rutting at the beginning of the test period which intensified as the traffic increased. Around the end of the summer, 3N01 North was scarified and graded. Then two different dust-oil applications were placed on the surface. A more detailed discussion of the oil layer application is presented earlier in this report.

80. A summary of the traffic data on site 5 showing the weekly accumulative vehicle operations is presented in Table 4. Since this

was a one-lane road, Table 4 includes the traffic in both directions. The final accumulative vehicle count on site 5 included 2536 log trucks, 1051 medium trucks, and 5723 other vehicles for a total count of 9310 vehicles. One half or 1268 of the log trucks were loaded while the other half were empty. The loaded log trucks were southbound toward Cottonwood Road while the empty trucks were northbound.

81. The cross-section data gathered on site 5 are presented graphically in Figure 13. Cross sections were made at six different operation levels at each station. Figure 17 shows the profile data obtained on the interior section of the profile line No. 2. These profiles indicate that the site 5 roadway had a slope of about 4.0 percent downhill. While Figure 17 shows only a slight change in the profile elevations from one traffic level to another, Figure 13 shows that there was considerable change in the cross sections with pronounced rutting. This rutting increased steadily until the middle of the testing period. At this time 3N01 North was graded and oiled causing the cross sections to be relatively smooth again. The last cross-section measurements show that the road surface was getting rough again.

82. Before the initial grading on site 5, three different sets of rut depth measurements were made with a 10-ft straightedge. These measurements are presented in Table 7 with the accompanying testing dates and accumulative traffic operations. Table 8 lists the rut depths as determined from the cross-section measurements.

83. Table 9 lists the results from the SAT on site 5 along with the testing dates and traffic levels. Initially the CBR on the road surface at site 5 was 26 while subsequent testing measured CBR's of 66, 73, and 52 on the surface. Measured values for the CBR at the top of the subgrade were 13, 18, 25, and 23, while at 12 in. into the subgrade CBR values of 11, 3.5, 7, and 13 were determined. Table 9 also lists the water content and dry density of the soil.

84. Figure 20 shows the gradation curve and Atterberg limits of a soil sample removed from the subgrade of site 5. The classification of this soil was determined to be SM.[3] The laboratory compaction and CBR data for the site 5 subgrade material are given in Figure 25a for

as-molded unsoaked samples and in Figure 25b for soaked samples.

Site 6

85. This site was situated on 2N89, an unsurfaced secondary road that intersected Cottonwood Road. The section of road associated with site 6 was a three-rut roadway on an essentially zero cut with the loaded log trucks traveling south toward Cottonwood and the empty log trucks traveling north. The general location in the logging area of site 6 is shown in Figure 1. Figure 7 is an illustration of the plan view and profile view of site 6.

86. In contrast to site 5 which had no maintenance, site 6 experienced heavy maintenance throughout the testing period. This maintenance, consisting primarily of grading and watering the road, is described in detail earlier in this report.

87. The week-by-week accumulative traffic on site 6 is summarized in Table 5 which combines the traffic in both directions as most vehicles traveled along the center of this narrow road. The vehicles moved to the edge of the road only when encountering traffic in the other direction. During the tests there were 15,442 log trucks and 12,296 other vehicles or a total of 27,738 vehicles passing over site 6. Half the log trucks or 7,721 vehicles were loaded while the other half were empty.

88. The cross-section data from site 6 are depicted in Figure 14 while profiles along the interior 100 ft of profile line No. 1 are presented in Figure 17. The profile data indicate that the road at site 6 sloped downhill at a rate of about 3.0 percent. The cross-section data in Figure 14 were measured on three different days. There was often considerable change in the elevation of any given point from one day to another resulting from the combination of traffic and maintenance. The general shape of the cross sections remained the same with some noticeable rutting. Some straightedge measurements to determine rut depths were made during the testing period, but insufficient traffic between maintenance cycles yielded no noticeable change in rut depths.

89. A tabulation of the SAT results is listed in Table 9 along with the testing dates and traffic volume. The initial testing measured a CBR of 25 on the road surface and a CBR of 20 12 in. below the surface. A month later a CBR of 9 was measured on the surface and a CBR of 12 was measured 12 in. below the surface. No SAT was performed at the end of the field tests because no change in surface deterioration could be measured. The water content and dry density of the soil for each CBR test location are included in Table 9.

90. A 500-lb disturbed soil sample of the subgrade from site 6 was sent to WES for laboratory testing. The gradation curve of this sample is shown in Figure 21. The soil was nonplastic and was classified as SM according to the USCS.[3] Figures 26a and 26b present the laboratory compaction and CBR data for the site 6 subgrade as determined according to Standard Military Methods 100 and 101.[2] The CBR data in Figure 26a are for specimens tested in the as-molded unsoaked condition and the data in Figure 26b are for specimens tested after soaking.

Site 7

91. Site 7 was the only test site not in the log-hauling area. This site was located on Herring Creek Road, which was a narrow unsurfaced two-lane road about 20 miles north of Cottonwood Road. The plan and profile views of site 7 are illustrated in Figure 8.

92. The weekly accumulative vehicle operations on site 7 are given in Table 6. The traffic in both directions are combined in Table 6 as the middle part of the road was usually traveled by vehicles going in either direction. By the end of the testing period there had been a total of 6791 vehicle operations on site 7. The type of traffic on site 7 consisted primarily of either light recreational vehicles or light FS vehicles.

93. Since this site was not selected until the middle of the summer, only two sets of cross-section and profile data were collected. These cross-section data are shown in Figure 15 and the profile data are shown in Figure 17. Only one profile line was established on site 7

since it was considered that one profile would be representative of the entire road. The profile data in Figure 17 show that site 7 was graded about two weeks after the initial set of cross sections and profiles were made. The final series of cross-section and profile measurements show that no significant deterioration occurred.

94. Table 9 gives the results of the SAT on site 7. Only one SAT set was conducted on site 7 occurring at the beginning of the observation period of this site. The CBR on the surface of the road was 52 and the CBR 12 in. below the surface was 13. The water content and dry density of the soil are included in Table 9. Since there was no apparent change in the road surface at the end of the testing, no other SAT was conducted on site 7.

PART IV: ANALYSIS

Structural Analysis

Flexible pavements

95. The initial step in analyzing the performance of the roads in the test sites was to predict the amount of traffic a particular road should have carried using the present Corps of Engineers design criteria. The next step was to compare this predicted failure traffic level with the actual amount of traffic during the testing period. For comparison with the design failure level, the number of passes of the various types of vehicles using the roads had to be converted to an equivalent number of passes of a single loading type. For the flexible pavements in test sites 1 through 4, the total traffic was converted to an equivalent number of standard, 18,000-lb, single-axle, dual-wheel loads. The conversion factors used to convert one pass of a given vehicle into an equivalent number of 18-kip axle passes were taken from "Revised Method of Thickness Design for Flexible Highway Pavements at Military Installations,"[4] and are listed in Table 10.

96. To obtain these conversion factors it was necessary to determine the axle loads on the different vehicles. The weight of the loaded log trucks shown in Table 10 was based on a sample of axle weights made at a truck weighing station on Cottonwood Road. The weights of the empty log trucks, the medium trucks, and the light vehicles were approximated since they were not critical. The number of operations of each vehicle type was then multiplied by the appropriate conversion factor as shown in Table 11 to obtain the total equivalent 18-kip axle operations. The predicted number of 18-kip axle operations required to produce failure were calculated using the Corps of Engineers design criteria.[4] The calculations were based on the pavement structural properties of sites 1 through 4 and are shown in Table 11.

Unsurfaced and gravel surfaced

97. In analyzing the performance of the unpaved roads in the test sites all traffic operations were converted into an equivalent

number of loaded log-truck tandem axle operations. The conversion factors for the unpaved roads were calculated using Hammitt's criteria[5] and are listed in Table 12. The total equivalent 34-kip tandem axle operations listed in Table 13 were calculated by multiplying the number of operations of each vehicle type by the appropriate conversion factor. The number of 34-kip tandem axle operations to failure was predicted based on the Corps of Engineers design criteria[5] and the pavement structural properties as shown in Table 13.

Deterioration

Rut depth analysis

98. The only significant rut depth measurements made during the testing period were at site 5. The first step in analyzing the rut depth measurements on site 5 was to determine if the rut depths increased with traffic as expected. From the straightedge measurements of Table 7, it was noted that the rut depth data at 25 of the 34 measuring locations showed a consistent increase with an increase in traffic. The data from the other nine points where the rut depths were measured showed the rut depth either remaining constant or decreasing. The data indicated there was a significant increase in the rut depths with traffic. The measurements from the nine places showing a constant or decreasing rut depth were considered erroneous or nontypical.

99. Of the remaining 25 locations, 14 places had rut depth measurements made at three different dates while 11 places were measured on two dates. The data from these 25 locations were averaged and are listed in Table 14 along with the testing data and accumulative traffic for site 5. In addition to the actual traffic on site 5, the number of equivalent 34-kip tandem axles that this traffic represents, calculated using the conversion factors of Table 12, are also given in Table 14. The data from Table 14 were then plotted as rut depth versus total vehicle operations in Figure 27, and as rut depth versus equivalent 34-kip tandem axle operations in Figure 28. Since the three points in each figure representing the average rut depth for the 14 locations measured

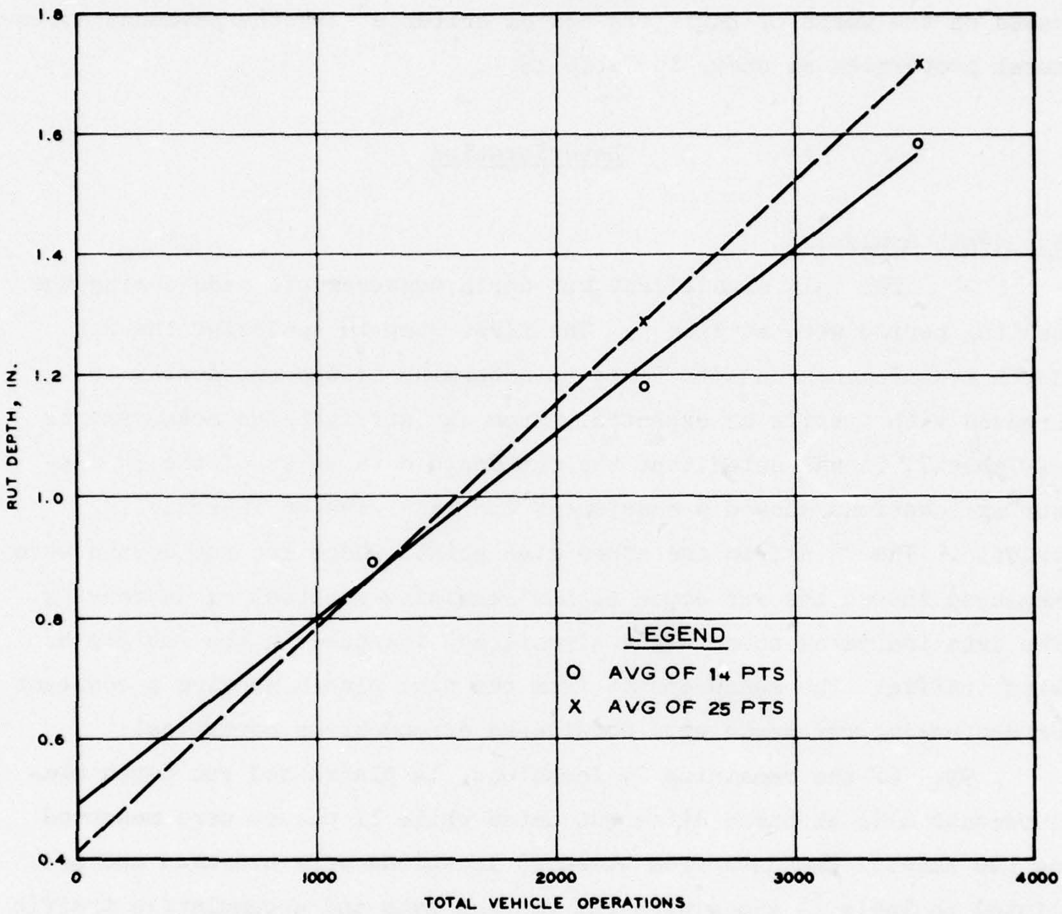


Figure 27. Rut depth versus total vehicle operations (straightedge data)

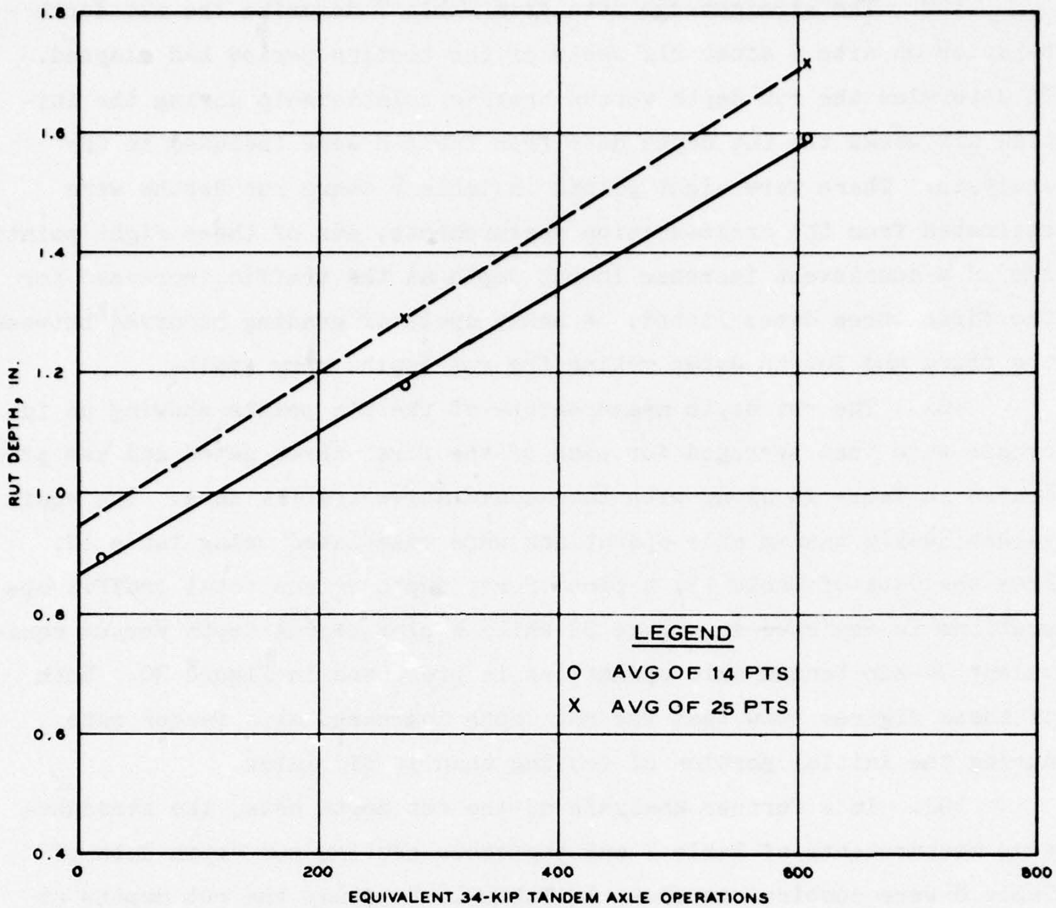


Figure 28. Rut depth versus equivalent 34-kip tandem axle operations (straightedge data)

on three different dates are approximately on a straight line, a linear regression analysis was run for these data. The resulting best fit lines are shown in Figures 27 and 28. Since the linear regression line of Figure 28 is a closer fit than the line of Figure 27, it indicates that the plot of rut depth versus equivalent 34-kip tandem axle is a linear relationship. The dashed line in Figures 27 and 28 connects the two data points representing the average rut depth for all 25 locations. This line was then extrapolated to zero traffic operations. It approximately parallels the best fit line of Figure 28 but intersects the best fit line of Figure 27.

100. The straightedge data from Table 7 describe the rut depth behavior on site 5 after six weeks of the testing period had elapsed. To determine the rut depth versus traffic relationship during the initial six weeks the rut depth data from Table 8 were included in the analysis. There were eight points in Table 8 where rut depths were estimated from the cross-section measurements; six of these eight points showed a consistent increase in rut depth as the traffic increased for the first three dates listed. A heavy cycle of grading occurred between the third and fourth dates making the rut depths very small.

101. The rut depth measurements of the six points showing an increase were then averaged for each of the first three dates and are presented in Table 15 along with the accumulative traffic data. The equivalent 34-kip tandem axle operations were calculated using Table 12. From the data of Table 15, a plot of rut depth versus total traffic operations is depicted in Figure 29 while a plot of rut depth versus equivalent 34-kip tandem axle operations is presented in Figure 30. Both of these figures show that the rut depth increased at a faster rate during the initial portion of testing than it did later.

102. In a further analysis of the rut depth data, the straightedge measurements of Table 7 and the cross-section rut depth data of Table 8 were combined as shown in Table 16 to study the rut depths at both of the wheel path locations at all four of the cross-section stations. As stated earlier in the report, there appeared to be a good correlation between the two methods of calculating the rut depth. For Table 16 an average value of the rut depth measurements of 19 and 20 June is given as well as the average accumulative traffic for these two dates.

103. Since the measured rut depth in the east wheel path at station 0+25 showed no apparent increase between 19 to 20 June and 27 July, these measurements were considered erroneous and were discarded. A few of the data points for the other seven locations appeared to be in error and were therefore adjusted. These adjustments were based on the assumption that from 19 June to 27 July the average rut depths varied linearly with the number of equivalent 34-kip tandem axle operations

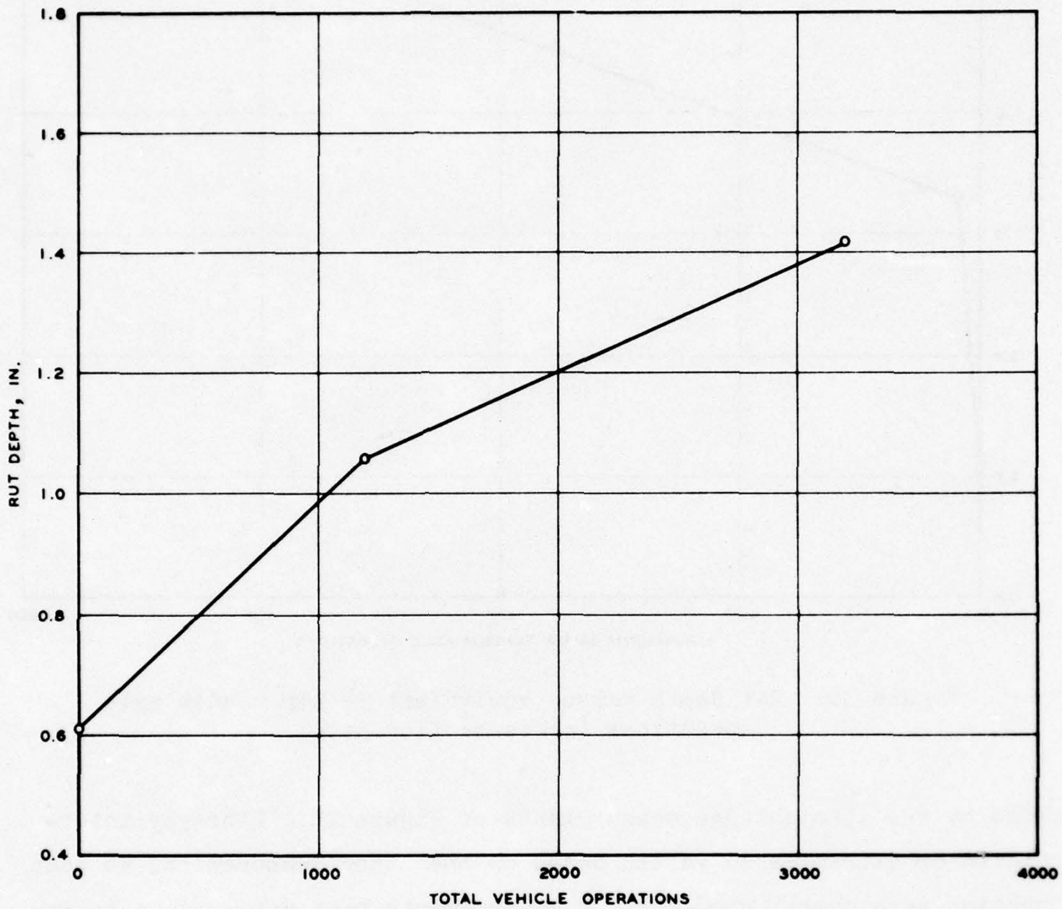


Figure 29. Rut depth versus total vehicle operations (cross-section data)

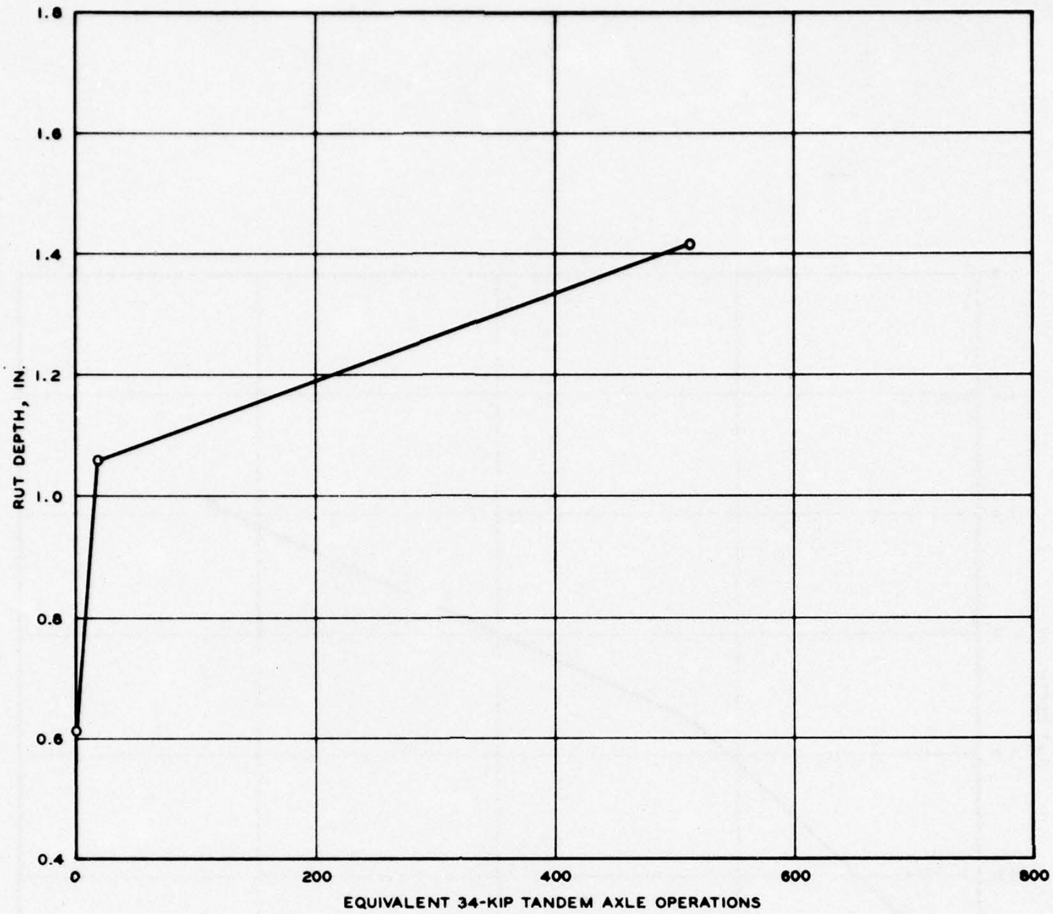


Figure 30. Rut depth versus equivalent 34-kip tandem axle operations (cross-section data)

shown by the straightedge measurements of Figure 28. Linearly interpolated or extrapolated values based on the other measurements at each location were substituted for the measurements that appeared to be erroneous. No adjustments were made for the initial measurements of 9 May. The rut depth values were then averaged for all seven locations as shown in Table 16 and plotted in Figure 31 as rut depth versus equivalent 34-kip tandem axle operations. A best fit line by a linear regression analysis is shown in Figure 31. This best fit line closely matches the best fit line of Figure 28 depicting the straightedge data. The dashed curve of Figure 31 represents the estimated rut depth during

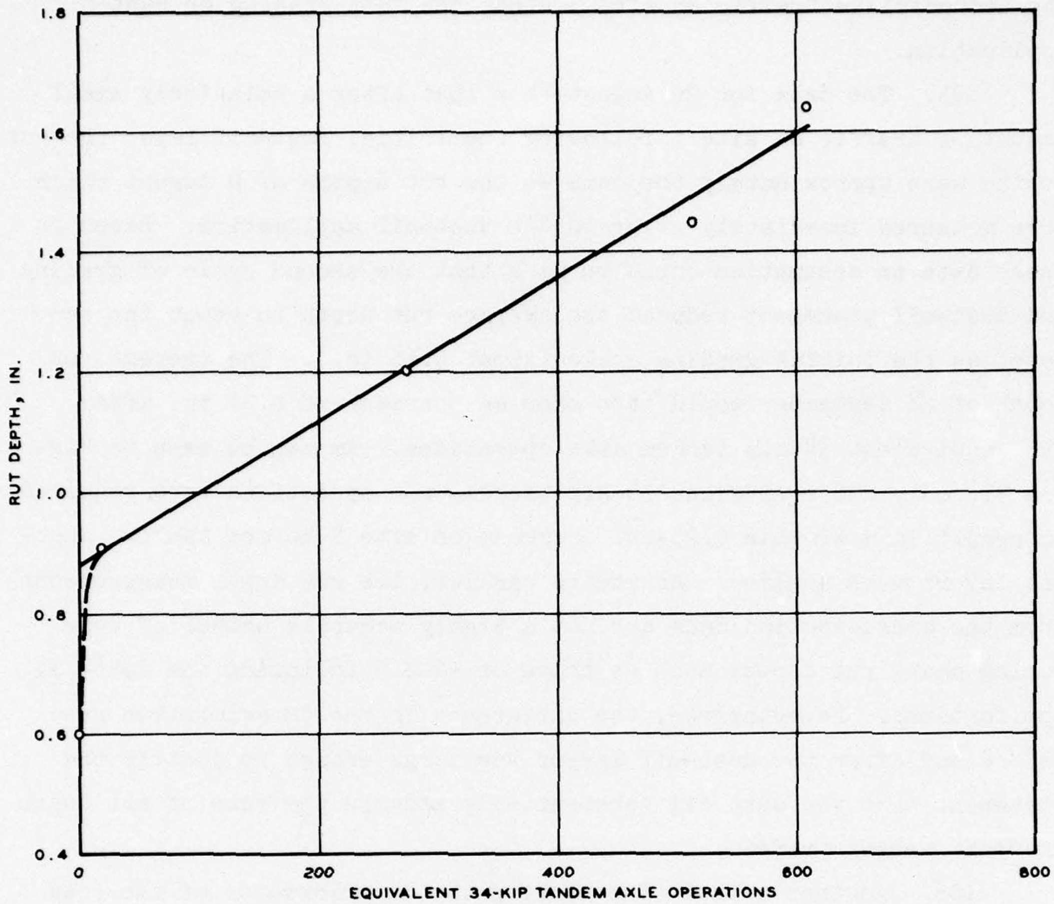


Figure 31. Rut depth versus equivalent 34-kip tandem axle operations (straightedge and cross-section data)

the initial six weeks of the testing period.

104. The only means available to determine the rut depth versus traffic relationship after the initial maintenance on site 5 were the rut depths calculated from the cross-section measurements. As can be seen in Table 8, cross-section measurements were made on three different dates after the initial grading on site 5 on 30 July. The calculated rut depths in Table 8 for these three dates were averaged and are shown in Table 17, along with the traffic data. Included in Table 17 are the dates of the principal maintenance on site 5 as well as the traffic data for these dates. The two adjusted traffic columns in Table 17 show

the accumulative traffic on site 5 since the last grading or dust-oil application.

105. The data for 20 August show that after a relatively small amount of traffic on site 5 following the initial dust-oil layer the rut depths were approximately the same as the rut depths of 9 August which were measured immediately prior to the dust-oil application. Based on these data an assumption could be made that the second cycle of grading and dust-oil placement reduced the average rut depth to about the same level as the initial grading cycle (about 0.15 in.). The average rut depth of 28 September would then show an increase of 0.25 in. after 1931 equivalent 34-kip tandem axle operations. As can be seen in Figure 31, only 210 equivalent 34-kip tandem-axle operations were required to result in a similar 0.25-in. increase on site 5 before the two dust-oil layers were applied. As stated earlier, the rut depth measurements from the cross-section data are not a highly accurate method of measuring small rut depths such as those on site 5 following the dust-oil applications. Nevertheless, the difference in the deterioration rate before and after the dust-oil layers was large enough to justify the statement that the dust oil substantially reduced the rate of rut depth increase versus traffic.

106. Another method of measuring the deterioration of the road surface was to determine the change in the elevations of the cross-section measurements. For site 5, the change in the average elevation of the interior 10 ft of the four cross-section stations was selected to gage the surface deterioration. Since site 5 was located on a narrow one-lane section of road, the interior 10 ft of the roadway essentially covered the entire width of the road subjected to traffic. The changes in elevation from the initial readings of 9 May are listed in Table 18 for each of the cross-section stations along with the testing dates and accumulative traffic data. This table shows that the mean elevation of the road surface at site 5 underwent a gradual decrease during the testing period. During the first half of the testing, this decrease was caused by the traffic while during the latter half this decrease in elevation was caused by both traffic and extensive grading.

On the other hand, the two dust-oil applications should have partially offset the overall surface elevation decrease.

107. Table 19 shows the change in the mean elevation of the interior 16 ft of the four cross-section stations on site 6. Like site 5, the mean elevation of the road surface at site 6 was also decreased during the testing period. Since for both sites 5 and 6 this decrease in elevation was caused by both the traffic and road maintenance, it was impossible to determine a mathematical relationship of the change in surface elevation versus traffic.

108. As another indicator of the surface roughness of site 5, the cross-section measurements were used to calculate the standard deviation from the best fit line through each cross section. These calculated standard deviations (Table 20) are thus a function of both the rut depths and overall irregularity of the cross sections. Table 20 shows that the road surface of site 5 became consistently rougher until the initial cycle of maintenance of 5 to 9 August reduced the surface roughness to almost its initial level. The data for 20 August show the road surface remaining smooth after a small amount of traffic following the initial dust-oil layer. The data of 28 September show the road surface of site 5 becoming rough again after a considerable amount of traffic following the second application of the dust oil.

Densification and surface loss

109. The relationship expressing average rut depth as a function of operations is shown in Figure 31 for site 5. The mean cross-section elevations at various operation levels are shown in Table 18 for site 5. An inspection of Table 9 shows the base and subgrade density at the various operation levels. As the rut depths increased, as indicated in Figure 31, the mean elevation of the cross sections decreased. This is an indication of densification of materials and indicates a need for a review of the density values. The values shown in Table 9 for the aggregate-surfacing density on site 5 indicate an increase of approximately 5 percent in density. Similar inspection of the density values of the subgrade shows an increase of approximately 33 percent at the surface and 28 percent at a depth of 12 in. into the subgrade. These

factors indicate that although some surface loss occurred as a result of vehicle tire action at the surface, as observed at site 5, the primary cause of rutting and of the decrease in mean cross-section elevation was densification or compaction of the aggregate surfacing and the subgrade. The small increase in the density of the aggregate surfacing as compared with that of the subgrade shows that the subgrade sustained most of the densification.

110. Figure 20 gives a gradation curve for the SM that constituted the subgrade at site 5. Figures 25a and 25b give the laboratory data for the soil at site 5, both as-molded and soaked. An inspection of the moisture-density relationships in Figures 25a and 25b, respectively, and comparison with the field densities for the subgrade shown in Table 9 indicates that the as-constructed densities at site 5 were less than those obtained in the laboratory at the minimum compactive effort. It is therefore concluded that the low initial subgrade densities at site 5 resulted in the rutting and mean loss in elevations as the road was subjected to traffic.

111. Since visual inspection indicated some surface loss from the roadway and since site 5 was located in a tangent area, it is believed necessary to conduct comparative tests in a curved area to determine what additional deterioration would occur by additional possible surface loss.

112. No appreciable rut depths or decrease in mean cross-section elevation were detected for the remaining test sites.

Profile roughness analysis

113. An analysis of the surface roughness of the seven test sites at various traffic levels was conducted using the profile data as illustrated in Figures 16 and 17. The Root-Mean-Square elevation (RMS) was computed for each profile. Random profiles were generated that represent each profile (or set of profile elevations) at each site. From these random profiles the RMS elevation or roughness number was computed for each site using pertinent portions of the AMC-71 Ground Mobility Model.[6] The roughness numbers of the profiles are given in Table 21. Relationships of roughness numbers as a function of operations for each

test site are given in Figure 32. A study of the data presented in Table 20 and Figure 32 shows that with the exception of site 5 and some

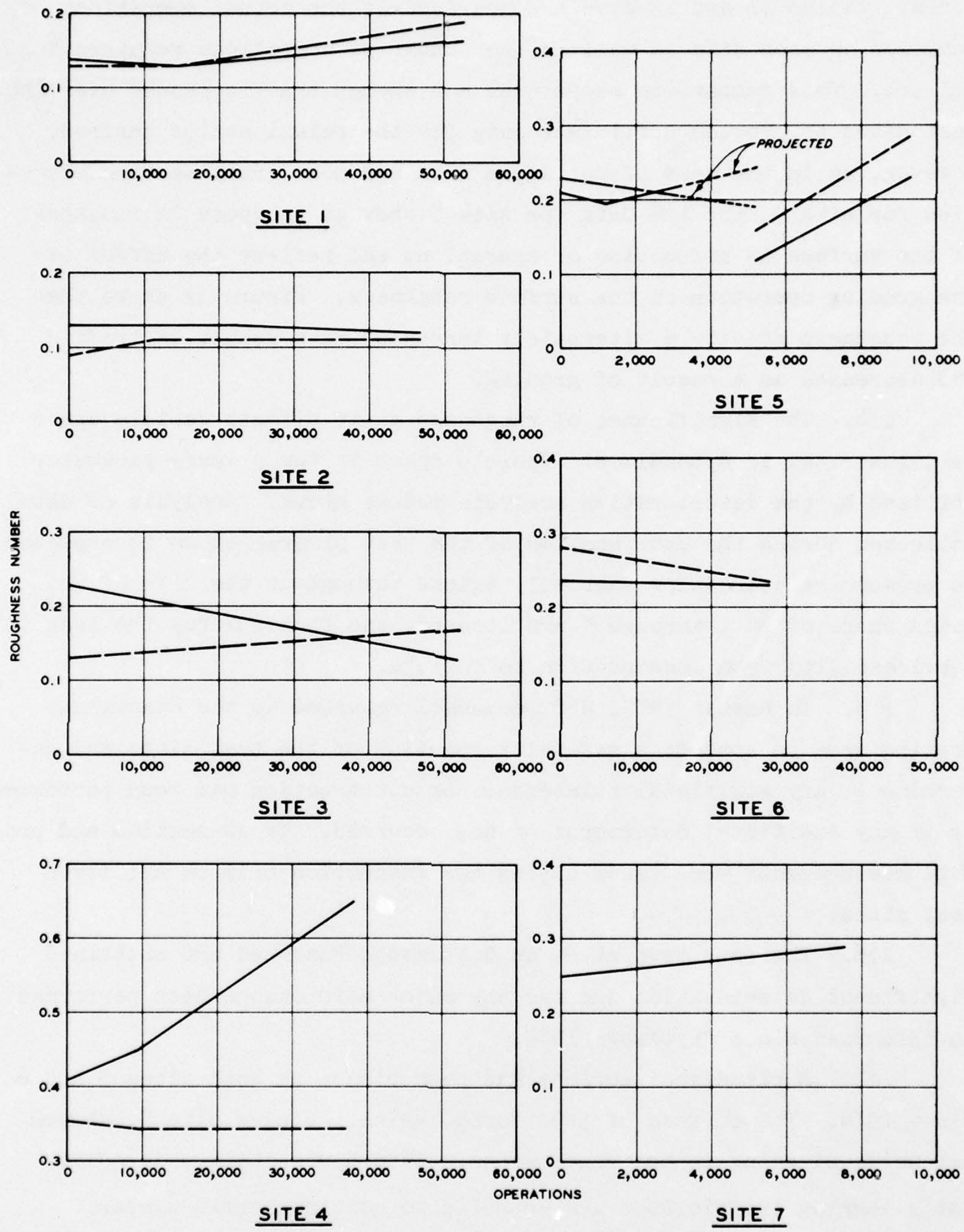


Figure 32. Road roughness numbers versus total vehicle operations

of the other site profiles, no clear-cut relationships were developed due to the relatively low number of traffic operations on the respective sites. Tables 11 and 13 give a comparison of the actual operations of vehicles on each site as well as the number of operations required for failure. This comparison shows that not enough traffic passed over the test sites to provide sufficient data for the relationships desired. However, as in the case of rut depth data and mean cross-section elevation for site 5, the RMS data for site 5 show an increase in roughness of the surface as a function of operations and reflect the effect of the grading operation on the surface roughness. Figure 32 shows that the roughness at site 5 alternately increased as a result of traffic and decreased as a result of grading.

114. The significance of roughness as it affects vehicle speed is illustrated in Appendix A. Vehicle speed is the primary parameter utilized by the deterioration analysis module shown. Analysis of data collected during the continuation of the test program shown is expected to produce relationships that will extend throughout the life of the roads where sites 1 through 7 are located, and thus portray the loss in serviceability from construction to failure.

115. In August 1975, WES personnel returned to the Stanislaus testing area to conduct a general inspection of the test sites and determine if any additional maintenance or construction had been performed, or if any additional deterioration had occurred. Cross-section and profile measurements were taken during the inspection trip on all seven test sites.

116. The four test sites on Cottonwood Road had not sustained significant deterioration nor had any major maintenance been performed on this road since September 1974.

117. A bituminous surface had been placed on both sites 5 and 6 since 1974. The surface of 3N01 North, which includes site 5, showed extensive bleeding in the wheel paths. Site 5 was still undergoing daily logging traffic that was expected to continue until winter.

118. The logging traffic on site 6 on 2N89 had ceased in the fall of 1974. Since all of 2N89 was in a burned area, site 6 had practically

no recreational traffic. Thus there was very little traffic on site 6 to cause deterioration.

119. Site 7, located on Herring Creek Road, was still having a considerable amount of recreational traffic. Some deterioration had occurred since site 7 had been graded last in the spring of 1975, but the site was not close to failure.

PART V: RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

Summary of Results

120. The field testing, test results, and an analysis of the results presented in this report are summarized as follows:

- a. The relatively small quantity of traffic on the roads where test sites were located and the short duration of testing did not permit sufficient traffic operation to provide comprehensive deterioration relationships.
- b. The intense log-hauling operation and the policy of extensive and frequent road maintenance precluded successful collection of data in an environment of road deterioration.
- c. An analysis of results in terms of rutting and roughness as related to traffic operations shows that tests of this nature, on a more sustained basis and under more favorable conditions, will provide for development of tenable and comprehensive deterioration relationships that extend over the life of the road.
- d. Although surface loss can be a contributing factor to rutting, the rutting that occurred at site 5 was chiefly the result of densification in the subgrade material.
- e. The roughness as depicted by rutting versus operation relationships adequately describes the functional deterioration of all sites for the amount of traffic shown and can be successfully extended by continuation of the test program.

Conclusions

121. Based upon this study and its results, the following conclusions are considered appropriate:

- a. A sustained deterioration analysis research program similar to that described herein will provide for comprehensive road deterioration relationships.
- b. Rutting and roughness are a function, in part, of the traffic operations on a road and can be utilized as descriptive parameters of deterioration.
- c. Continued tests of the type described herein can only be successful when the parties involved cooperate to ensure a suitable testing environment in terms of roads,

traffic, and maintenance practices.

_d_. Road deterioration analysis capabilities developed as a result of tests of this type will provide a significant improvement in the state of the art of road serviceability prediction, road maintenance needs, and user maintenance cost assessments.

_e_. Any developments in road deterioration relationships must be in terms of parameters sufficient to accommodate certain recognized empirical procedures and must be expressed in terms that can be used in theoretical or rational design concepts, insofar as possible.

_f_. The deterioration analysis concept presented in Appendix A improves the capability to estimate the worth of a road and its future maintenance needs.

_g_. The probability of improving the preliminary relationships developed and utilizing them in the deterioration analysis modules to improve life cycle management capabilities is extremely high.

Recommendations

122. In view of the tentative relationships developed as a result of data collected during a brief, austere test program and in view of the successful development of deterioration analysis capabilities, the following recommendations are believed warranted:

_a_. A pavement deterioration program aimed at improving present capabilities in beginning-to-end design, maintenance, and rehabilitation of roads similar to the program outlined in this report should be pursued to the greatest extent possible.

_b_. This program should be aimed at the validation of the deterioration analysis module in Appendix A and the distortion and fatigue models currently in existence as well as being applicable to all pavement types and capable of augmenting other pertinent models.

_c_. All concerned agencies having a need to improve their capabilities in design, maintenance, rehabilitation, and evaluation of roads and other related facilities should consider participation in such a program.

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Table 1

Summary of Traffic Data, Sites 1 and 3*

(Westbound Lane, Cottonwood Road)

1974 Date		Accumulative Operations			
From	To	Log Trucks	Medium Trucks	Other Vehicles	Total Vehicles
8 May	10 May	820	76	304	1,200
	17 May	2,192	217	1,041	3,450
	24 May	3,586	360	1,754	5,700
	31 May	4,733	543	2,749	8,025
	7 Jun	6,178	763	3,447	10,388
	14 Jun	7,373	957	4,016	12,346
	21 Jun	8,913	1146	5,084	15,143
	28 Jun	10,534	1387	6,223	18,144
	5 Jul	11,586	1565	7,071	20,222
	12 Jul	12,569	1746	8,080	22,395
	19 Jul	14,187	2411	9,185	25,783
	26 Jul	15,812	3075	10,029	28,916
	2 Aug	17,465	3757	10,747	31,969
	9 Aug	19,109	4219	11,929	35,257
	16 Aug	20,697	4476	12,997	38,170
	23 Aug	22,273	4659	14,033	40,965
	30 Aug	23,910	4838	14,919	43,667
	6 Sep	25,280	5077	15,558	45,915
	13 Sep	26,847	5269	16,195	48,311
	20 Sep	28,272	5379	17,161	50,812
	27 Sep	29,661	5490	17,951	53,102

* Although traffic on sites 1, 2, and 3 was registered on the same counter, site 2 traffic data were adjusted for local conditions and are presented in Table 2 (see paragraphs 34 and 61 in the main text).

Table 2

Summary of Traffic Data, Site 2

(Westbound Lane, Cottonwood Road)

1974 Date		Accumulative Operations			
From	To	Log Trucks	Medium Trucks	Other Vehicles	Total Vehicles
8 May	10 May	449	76	304	829
	17 May	1,200	217	1,041	2,458
	24 May	2,271	360	1,754	4,385
	31 May	2,988	543	2,749	6,280
	7 Jun	3,914	763	3,447	8,124
	14 Jun	4,680	957	4,016	9,653
	21 Jun	5,766	1146	5,084	11,996
	28 Jun	6,909	1387	6,223	14,519
	5 Jul	7,651	1565	7,071	16,287
	12 Jul	8,347	1746	8,080	18,173
	19 Jul	9,493	2411	9,185	21,089
	26 Jul	10,644	3075	10,029	23,748
	2 Aug	12,190	3757	10,747	26,694
	9 Aug	13,728	4219	11,929	29,876
	16 Aug	15,214	4476	12,997	32,687
	23 Aug	16,688	4659	14,033	35,380
	30 Aug	18,219	4838	14,919	37,976
	6 Sep	19,501	5077	15,558	40,136
	13 Sep	20,967	5269	16,195	42,431
	20 Sep	22,300	5379	17,161	44,840
	27 Sep	23,599	5490	17,951	47,040

Table 3

Summary of Traffic Data, Site 4

(Westbound Lane, Cottonwood Road)

1974 Date		Accumulative Operations			
From	To	Log Trucks	Medium Trucks	Other Vehicles	Total Vehicles
8 May	10 May	656	61	243	960
	17 May	1,754	169	766	2,689
	24 May	2,869	278	1,258	4,405
	31 May	3,786	418	1,975	6,179
	7 Jun	4,942	594	2,459	7,995
	14 Jun	5,898	744	2,818	9,460
	21 Jun	7,130	883	3,591	11,604
	28 Jun	8,416	1070	4,382	13,868
	5 Jul	9,223	1190	4,938	15,351
	12 Jul	9,981	1316	5,640	16,937
	19 Jul	11,236	1833	6,390	19,459
	26 Jul	12,493	2345	6,904	21,742
	2 Aug	13,757	2868	7,330	23,955
	9 Aug	15,040	3224	8,103	26,367
	16 Aug	16,302	3418	8,813	28,533
	23 Aug	17,534	3550	9,506	30,590
	30 Aug	18,765	3662	10,112	32,539
	6 Sep	19,742	3820	10,476	34,038
	13 Sep	20,849	3920	10,890	35,659
	20 Sep	21,803	3954	11,576	37,333
	27 Sep	22,714	3975	12,083	38,772

Table 1

Summary of Traffic Data, Site 5

(Both Directions, 3N01 North)

1974 Date From	To	Accumulative Operations Log Trucks	Medium Trucks	Other Vehicles	Total Vehicles
10 May	31 May	0	0	560	560
	7 Jun	0	40	745	785
	14 Jun	0	53	985	1038
	21 Jun	0	83	1190	1273
	28 Jun	28	97	1492	1617
	5 Jul	114	154	1798	2066
	12 Jul	186	202	2060	2448
	19 Jul	284	239	2395	2918
	26 Jul	392	288	2797	3477
	2 Aug	538	344	3170	4052
	9 Aug	618	378	3598	4594
	16 Aug	638	407	3961	5006
	23 Aug	710	444	4299	5453
	30 Aug	908	519	4558	5985
	6 Sep	1206	604	4925	6735
	13 Sep	1572	737	5163	7472
	20 Sep	2036	873	5381	8290
	27 Sep	2536	1041	5693	9270
	28 Sep	2536	1051	5723	9310

Table 5

Summary of Traffic Data, Site 6

(Both Directions, 2N89)

1974 Date		Accumulative Operations			
From	To	Log Trucks	Medium Trucks	Other Vehicles	Total Vehicles
22 Jun	28 Jun	456	--	445	901
	5 Jul	773	--	752	1,525
	12 Jul	1,062	--	1,118	2,180
	19 Jul	1,726	--	1,763	3,489
	26 Jul	3,118	--	3,060	6,178
	2 Aug	4,497	--	4,360	8,857
	9 Aug	5,572	--	5,397	10,969
	16 Aug	6,686	--	6,511	13,197
	23 Aug	8,013	--	7,794	15,807
	30 Aug	9,451	--	9,179	18,630
	6 Sep	10,780	--	9,926	20,706
	13 Sep	12,438	--	10,791	23,229
	20 Sep	14,028	--	11,615	25,643
	27 Sep	15,442	--	12,296	27,738

Table 6

Summary of Traffic Data, Site 7

(Both Directions, Herring Creek Road)

1974 Date From	To	Accumulative Operations* Total Vehicles
26 Jul	2 Aug	1047
	9 Aug	1910
	16 Aug	2766
	23 Aug	3631
	30 Aug	4724
	6 Sep	5372
	13 Sep	5918
	20 Sep	6315
	27 Sep	6791

* Site 7 was not in the log-haul area and received traffic consisting primarily of either light recreational or light FS vehicles (see paragraphs 91, 92, and 93 in the main text).

Table 7

Site 5 Rut Depths, Straightedge Measurements

1974 Date	Wheel Path	Accumulative Operations: Log Trucks	Medium Vehicles	Light Vehicles	Total Vehicles	Rut Depths, in. Sta No.: 0+00	0+12	0+25	0+37	0+50	0+62	0+75	--	0+87	1+00	1+12	1+25	1+37	1+50	1+62	1+75	1+87	2+00
20 Jun	East	0	82	1151	1233	1.5	1.0	1.25	1.25	0.75	1.0	--	--	--	--	--	--	--	--	0.75	0.5	0.75	0.75
11 Jul	East	164	194	2004	2362	1.1	1.2	1.2	1.0	1.3	1.3	1.6	--	1.8	1.4	1.4	1.2	1.2	0.8	0.6	0.5	0.8	1.1
27 Jul	East	392	292	2833	3517	1.1	1.1	1.2	1.4	1.4	1.5	2.8	--	2.7	2.0	1.7	1.2	1.3	1.2	0.6	0.9	1.3	1.2
20 Jun	West	0	82	1151	1233	1.5	1.0	0.75	0.75	1.0	0.5	--	--	--	--	--	--	--	--	1.25	1.25	1.0	0.75
11 Jul	West	164	194	2004	2362	1.6	1.3	1.2	0.9	0.8	0.7	1.3	--	1.6	1.5	1.2	1.5	1.7	1.5	1.4	1.9	1.4	1.1
27 Jul	West	392	292	2833	3517	2.1	1.6	1.6	1.4	0.9	1.2	1.2	--	1.9	1.5	1.4	2.0	1.9	1.7	1.9	2.1	2.2	1.9

Table 8

Site 5 Rut Depths, Cross-Section Measurements

1974 Date	Wheel Path	Accumulative Operations: Log Trucks	Medium Trucks	Light Vehicles	Total Vehicles	Rut Depths, in.: Sta 0+25	Sta 0+75	Sta 1+25	Sta 1+75
9 May	East	0	0	0	0	0.66	0.88	0.60	0.30
19 Jun	East	0	80	1108	1188	1.06	0.42	0.66	0.40
23 Jul	East	326	266	2606	3198	1.25	2.11	1.32	0.34
9 Aug	East	618	378	3598	4594	0.00	0.32	0.06	0.06
20 Aug	East	646	424	4137	5207	0.20	0.00	0.06	0.12
28 Sep	East	2536	1051	5723	9310	0.34	0.62	0.24	0.24
9 May	West	0	0	0	0	0.46	0.40	1.00	0.56
19 Jun	West	0	80	1108	1188	1.03	0.82	1.58	1.18
23 Jul	West	326	266	2606	3198	1.46	1.08	1.73	1.68
9 Aug	West	618	378	3598	4594	0.28	0.17	0.18	0.24
20 Aug	West	646	424	4137	5207	0.24	0.32	0.06	0.12
28 Sep	West	2536	1051	5723	9310	0.84	0.24	0.36	0.36

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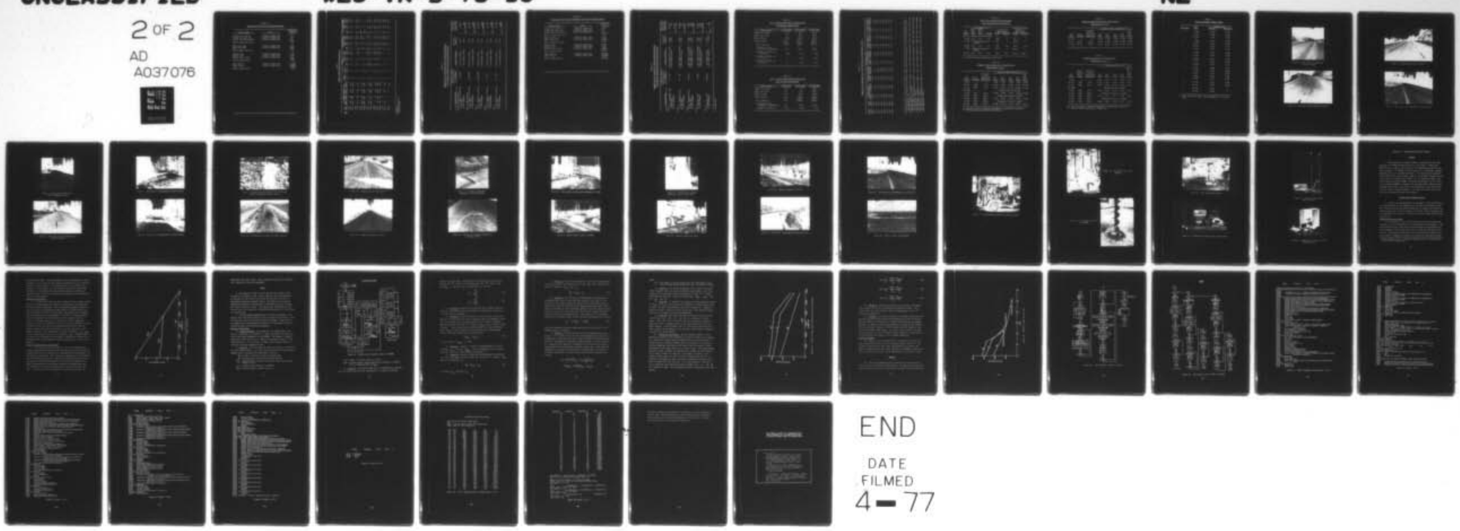

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Table 10

Conversion Factors for Flexible Pavements

Vehicle Type	Load	Conversion Factor
Loaded log truck cab	8,000-lb single axle	0.03
Loaded log truck cab	34,000-lb tandem axle	4.3
Loaded log truck trailer	34,000-lb tandem axle	4.3
Entire loaded log truck		8.63
Empty log truck	8,000-lb single axle	0.03
Empty log truck	17,000-lb tandem axle	0.18
Entire empty log truck		0.21
Medium truck	5,500-lb single axle	0.007
Medium truck	15,000-lb tandem axle	0.10
Medium truck trailer	15,000-lb tandem axle	0.10
Entire medium truck		0.207
Light vehicle	2,000-lb single axle	0.0005
Light vehicle	2,000-lb single axle	0.0005
Entire light vehicle		0.001

Table 9

Summary of CBR, Water Content, and Density Data

Site No.	1974 Date	Accumulative Operations: Log Trucks	Medium Trucks	Other Vehicles	Total Vehicles	Asphalt Thickness in.	Base: Thickness in.	Base: CBR	Base: Water Content %	Base: Dry Density pcf	Top of Subgrade: CBR	Top of Subgrade: Water Content %	Top of Subgrade: Dry Density pcf	12 In. into Subgrade: CBR	12 In. into Subgrade: Water Content %	12 In. into Subgrade: Dry Density pcf
1	7 May	0	0	0	0	6	3	61	5.2	148.8	13	10.9	128.5	13	10.4	107.1
	19 Jun	8,273	1086	4,759	14,118	6	3	63	6.5	144.8	41	13.9	122.7	26	11.4	132.8
	28 Jun	10,534	1387	6,223	18,144	8*	3	--	--	--	--	--	--	--	--	--
2	7 May	0	0	0	0	7	3	15	--	--	17	14.9	119.2	39	16.0	127.4
	19 Jun	5,314	1086	4,759	11,159	7	3	68	5.5	146.6	26	15.4	114.1	82	13.7	135.1
3	8 May	0	0	0	0	0	0	--	--	--	80	5.1	125.8	100**	4.4	--
	23 Jun	8,913	1235	5,333	15,481	0	0	--	--	--	95	3.9	144.4	--	--	--
	24 Sep	28,828	5446	17,628	51,902	4*	9.5	40	7.4	--	82	5.6	--	100**	--	--
4	8 May	0	0	0	0	0	9	95	3.4	143.6	19	15.4	97.3	32	15.7	95.7
	23 Jun	7,130	952	3,750	11,832	0	9	100**	1.3	148.9	24	11.7	98.6	22	19.3	101.8
	24 Sep	22,168	3971	11,897	38,036	4*	9	110	3.4	--	32	7.1	--	10	20.4	--
5	9 May	0	0	0	0	0	12†	26	6.3	125.6	13	28.6	70.1	11	32.4	69.1
	19 Jun	0	80	1,108	1,188	0	12	66	6.8	126.4	18	26.3	75.1	3.5	29.9	75.4
	23 Jul	326	266	2,606	3,198	0	12	73	5.1	133.2	25	16.0	84.7	7	31.6	74.7
	28 Sep	2,536	1051	5,723	9,310	0	12	52	4.0	132.3	23	22.1	93.2	13	21.0	88.4
6	21 Jun	0	0	0	0	0	0	--	--	--	25	19.9	99.2	20	9.9	109.1
	26 Jul	3,118	--	3,060	6,178	0	0	--	--	--	9	19.9	103.6	12	17.9	94.4
7	25 Jul	0	0	0	0	0	0	--	--	--	52	11.8	114.0	13	16.5	106.0
	27 Sep	--	--	--	6,791	--	--	--	--	--	--	--	--	--	--	--

* Overlay.
** More than listed value.
† Subbase material.

Table 11

Comparison of Predicted 18-Kip Failure Operations with Vehicle Operations During Testing Period

Location Data	Predicted 18-kip Axle Operations to Failure	Actual Loading		Conversion Factor		Equivalent 18-kip Axle Operations
Site 1 before overlay						
6-in. asphaltic concrete	500,000	10,534 log trucks	×	8.63	=	90,908
3-in. base						
13 CBR subgrade		1,387 medium trucks	×	0.207	=	287
					Total	91,195
Site 1 after overlay						
8-in. asphaltic concrete	1,500,000	19,127 log trucks	×	8.63	=	165,066
3-in. base						
13 CBR subgrade		4,103 medium trucks	×	0.207	=	849
					Total	165,915
Site 2						
7-in. asphaltic concrete	20,000,000	23,599 log trucks	×	8.63	=	203,659
3-in. base						
17 CBR subgrade		5,490 medium trucks	×	0.207	=	1,136
					Total	204,795
Site 3						
4-in. asphaltic concrete	$>1 \times 10^9$	10,552 log trucks	×	8.63	=	91,064
9.5-in. base						
90 CBR subgrade		1,271 medium trucks	×	0.207	=	263
					Total	91,327
Site 4						
4-in. asphaltic concrete	$>1 \times 10^9$	8,957 log trucks	×	8.63	=	77,299
9-in. base						
24 CBR subgrade		1,107 medium trucks	×	0.207	=	229
					Total	77,528

Table 12

Conversion Factors for Unsurfaced and Gravel Surfaced Roads

Vehicle Type	Load	Conversion Factor
Loaded log truck cab	8,000-lb single axle	0.223
Loaded log truck cab	34,000-lb tandem axle	1.0
Loaded log truck trailer	34,000-lb tandem axle	1.0
Entire loaded log truck		2.223
Empty log truck	8,000-lb single axle	0.223
Empty log truck	17,000-lb tandem axle	0.322
Entire empty log truck		0.545
Medium truck	5,500-lb single axle	0.046
Medium truck	15,000-lb tandem axle	0.085
Medium truck trailer	15,000-lb tandem axle	0.085
Entire medium truck		0.216
Light vehicle	2,000-lb single axle	0.00058
Light vehicle	2,000-lb single axle	0.00058
Entire light vehicle		0.00116

Table 13

Comparison of Predicted 34-Kip Failure Operations with Vehicle Operations During Testing Period

Location Data	Predicted 34-kip Axle* Operations to Failure	Actual Loading		Conversion Factor		Equivalent 34-kip Axle* Operations
Site 3						
9.5-in. aggregate base	>1 × 10^8	19,109 loaded log trucks	×	2.223	=	42,479
40 CBR base		4,219 medium trucks	×	0.216	=	911
90 CBR subgrade						
					Total	43,390
Site 4						
9-in. aggregate base	>1 × 10^8	13,757 loaded log trucks	×	2.223	=	30,582
100 CBR base		2,868 medium trucks	×	0.216	=	619
24 CBR subgrade						
					Total	31,201
Site 5						
12-in. aggregate base	750,000	1,268 loaded log trucks	×	2.223	=	2,819
26 CBR base		1,268 empty log trucks	×	0.545	=	691
12 CBR subgrade		1,051 medium trucks	×	0.216	=	227
					Total	3,737
Site 6						
no aggregate base	35,000	7,721 loaded log trucks	×	2.223	=	17,164
16 CBR subgrade		7,721 empty log trucks	×	0.545	=	4,208
		1,000 medium trucks	×	0.216	=	216
					Total	21,588
Site 7						
no aggregate base	2,500,000	10 medium trucks	×	0.216	=	2
32 CBR subgrade		6,781 light vehicles	×	0.00116	=	8
					Total	10

* Tandem axle.

Table 14

Site 5 Traffic Data and Rut Depths from Straightedge Measurements

Vehicle Type	20 Jun 1974	11 Jul 1974	27 Jul 1974
Loaded log trucks	0.0	82.0	196.0
Empty log trucks	0.0	82.0	196.0
Medium trucks	82.0	194.0	292.0
Light vehicles	1151.0	2004.0	2833.0
Total vehicles	1233.0	2362.0	3517.0
Equivalent 34-kip tandem axle operations	19.0	271.2	608.9
Average rut depth, in. (14 points)	0.89	1.18	1.59
Average rut depth, in. (11 points)	--	1.43	1.87
Average rut depth, in. (25 points)	--	1.29	1.72

Table 15

Site 5 Traffic Data and Rut Depths from Cross-Section Measurements

Vehicle Type	9 May 1974	19 Jun 1974	23 Jul 1974
Loaded log trucks	0.0	0.0	163.0
Empty log trucks	0.0	0.0	163.0
Medium trucks	0.0	80.0	266.0
Light vehicles	0.0	1108.0	2606.0
Total vehicles	0.0	1188.0	3198.0
Equivalent 34-kip tandem axle operations	0.0	18.6	511.6
Average rut depth, in.	0.61	1.06	1.42

Table 16

Combined Straightedge and Cross-Section Rut Depth Data, Site 5

Station No.	Wheel Path	Rut Depth, in. 9 May 1974* Actual	Adjusted	19-20 Jun 1974** Actual	Adjusted	11 Jul 1974† Actual	Adjusted	23 Jul 1974†† Actual	Adjusted	27 Jul 1974‡ Actual	Adjusted
0+25	East	0.66	--	1.16	--	1.2	--	1.25	--	1.2	--
1+75	East	0.30	0.30	0.45	0.45	0.5	0.50	0.34	--	0.9	0.90
0+75	West	0.40	0.40	0.82	0.82	1.3	0.95	1.08	1.08	1.2	1.20
1+25	East	0.60	0.60	0.66	0.66	1.2	1.20	1.32	1.32	1.2	1.37
0+25	West	0.46	0.46	0.89	0.89	1.2	1.20	1.46	1.46	1.6	1.60
1+75	West	0.56	0.56	1.22	1.22	1.9	1.46	1.68	1.68	2.1	2.10
1+25	West	1.00	1.00	1.58	1.26	1.5	1.50	1.73	1.73	2.0	2.00
0+75	East	0.88	0.88	0.42	1.06	1.6	1.60	2.11	2.11	2.8	2.32

* For this date: avg adjusted rut depth = 0.60, total vehicle operations = 0, and total 34-kip tandem axle operations = 0.

** For this period: avg adjusted rut depth = 0.91, total vehicle operations = 1210, and total 34-kip tandem axle operations = 18.8.

† For this date: avg adjusted rut depth = 1.20, total vehicle operations = 2362, and total 34-kip tandem axle operations = 271.2.

†† For this date: avg adjusted rut depth = 1.45, total vehicle operations = 3198, and total 34-kip tandem axle operations = 511.6.

‡ For this date: avg adjusted rut depth = 1.64, total vehicle operations = 3517, and total 34-kip tandem axle operations = 608.9.

Table 17

Site 5 Rut Depths After Maintenance

From Cross-Section Measurements

1974 Date	Rut Depth, in. East Wheel Path	West Wheel Path	Average	Total Vehicle Operations Actual	Adjusted	Equivalent 34-kip Tandem Axle Operations Actual	Adjusted
5-9 Aug	Grading and scarifying*			--	--	--	--
9 Aug	0.11	0.22	0.16	4594	0	941.1	0
10 Aug	Grading and dust-oil layer*			4633	0	944.6	0
20 Aug	0.10	0.19	0.14	5207	574	990.4	45.8
7 Sep	Grading and dust-oil layer*			6794	0	1812.2	0
28 Sep	0.36	0.45	0.40	9310	2516	3743.5	1931.3

* Surface-altering maintenance operations.

Table 18

Change in Mean Elevation of Cross-Section

Measurements, Site 5

1974 Date	Total Vehicles	Equivalent 34-kip Tandem Axle Operations	Change in Mean Elevation, ft Sta 0+25	Sta 0+75	Sta 1+25	Sta 1+75	All Four Stations
9 May	0	0	0.000	0.000	0.000	0.000	0.000
19 Jun	1188	18.6	+0.010	-0.011	+0.025	+0.055	+0.020
23 Jul	3198	511.6	-0.028	-0.051	-0.051	-0.015	-0.036
5-8 Aug*			Grading and scarifying**				
9 Aug	4594	941.1	-0.040	-0.089	-0.087	-0.049	-0.066
10 Aug	4633	944.6	Grading and dust-oil layer**				
20 Aug	5207	990.4	-0.071	-0.114	-0.112	-0.077	-0.093
7 Sep	6794	1812.2	Grading and dust-oil layer**				
28 Sep	9310	3743.5	-0.080	-0.191	-0.093	+0.024	-0.085

* Data not taken or rendered meaningless by maintenance operation.
** Surface-altering maintenance operations.

Table 19

Change in Mean Elevation of Cross-Section

Measurements, Site 6

1974 Date	Total Vehicles	Equivalent 34-kip Tandem Axle Operations	Change in Mean Elevation, ft Sta 0+25	Sta 0+75	Sta 1+25	Sta 1+75	All Four Stations
21 Jun	0	0	0.000	0.000	0.000	0.000	0.000
26 Jul	6,178	4,372	-0.101	-0.033	-0.001	+0.033	-0.026
27 Sep	26,536	20,451	-0.124	-0.053	-0.076	+0.001	-0.063

Table 20

Standard Deviations of Cross-Section

Measurements, Site 5

1974 Date	Total Vehicles Operations	Equivalent 34-kip Tandem Axle Operations	Standard Deviation, ft Sta 0+25	Sta 0+75	Sta 1+25	Sta 1+75	Average of All Four Stations
9 May	0	0	0.023	0.023	0.031	0.018	0.024
19 Jun	1188	18.6	0.039	0.020	0.039	0.029	0.032
23 Jul	3198	511.6	0.048	0.058	0.053	0.045	0.051
5-8 Aug*			Grading and scarifying**				
9 Aug	4594	941.1	0.040	0.012	0.026	0.040	0.030
10 Aug	4633	944.6	Grading and dust-oil layer**				
20 Aug	5207	990.4	0.034	0.18	0.27	0.030	0.027
7 Sep	6794	1812.2	Grading and dust-oil layer**				
28 Sep	9310	3743.5	0.039	0.060	0.033	0.035	0.042

* Data not taken or rendered meaningless by maintenance operation.
** Surface-altering maintenance operations.

Table 21

Profile Roughness Numbers (RMS)

Test Site	1974 Date	Roughness No. Profile 1	Profile 2
1	7 May	0.138	0.134
	19 Jun	0.126	0.125
	24 Sep	0.167	0.193
2	7 May	0.133	0.091
	19 Jun	0.131	0.107
	23 Jul	0.133	0.112
	24 Sep	0.119	0.112
3	8 May	0.232	0.130
	24 Sep	0.160	0.169
4	8 May	0.412	0.358
	23 Jun	0.452	0.344
	24 Sep	0.651	0.344
5	9 May	0.209	0.229
	19 Jun	0.195	0.220
	23 Jul	0.222	0.203
	9 Aug	0.122	0.162
	28 Sep	0.234	0.282
6	21 Jun	0.218	0.279
	27 Sep	0.226	0.236
7	25 Jul	0.250	*
	27 Sep	0.288	*

* Only one profile taken (see paragraph 40 in the main text).

Photo 1. Test site 1 at beginning of field testing

Photo 2. Test site 1 after asphalt overlay

Photo 3. General view of test site 2

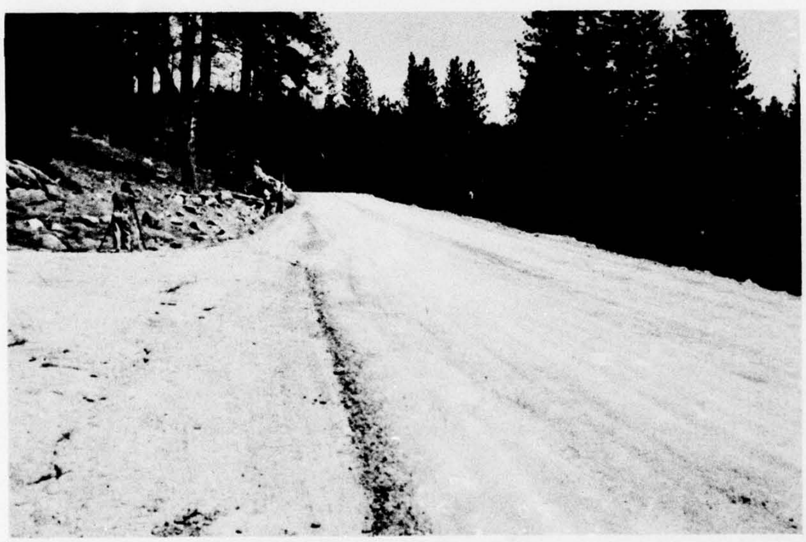

Photo 4. Test site 3 at beginning of field testing

Photo 5. Test site 3 after placement of aggregate base

Photo 6. Test site 3 after placement of asphalt surface

Photo 7. Test site 4 at beginning of field testing

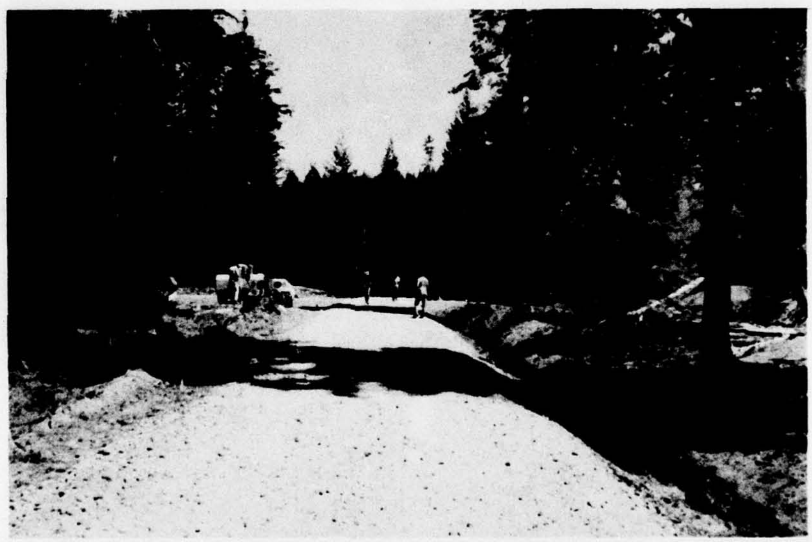

Photo 8. Test site 5 at beginning of field testing

Photo 9. Exposed cross section at site 5 showing depth of aggregate surface course

Photo 10. Deterioration of dust-oil layer on site 5

Photo 11. General view of test site 6

Photo 12. General view of test site 7

Photo 13. Failure of flexible pavement on Cottonwood Road

Photo 14. Failure of flexible pavement on Cottonwood Road

Photo 15. Motor grader performing maintenance on 2N89

Photo 16. Water truck at site 5 on 2N89

Photo 17. Electric eye counter mounted on tree at test site 5

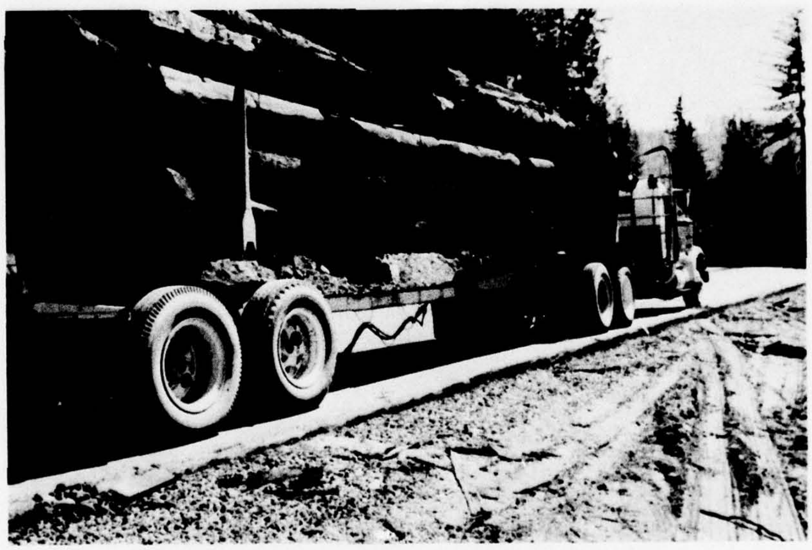

Photo 18. Typical loaded log truck

Photo 19. Typical unloaded log truck

Photo 20. Test site 1 being measured and marked off

Photo 21. Cross-section measurements on test site 3

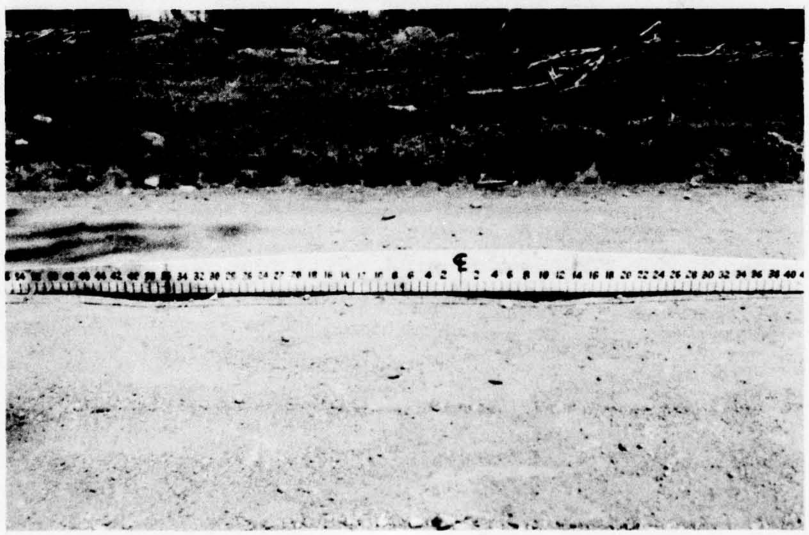

Photo 22. Standard 10-ft straightedge

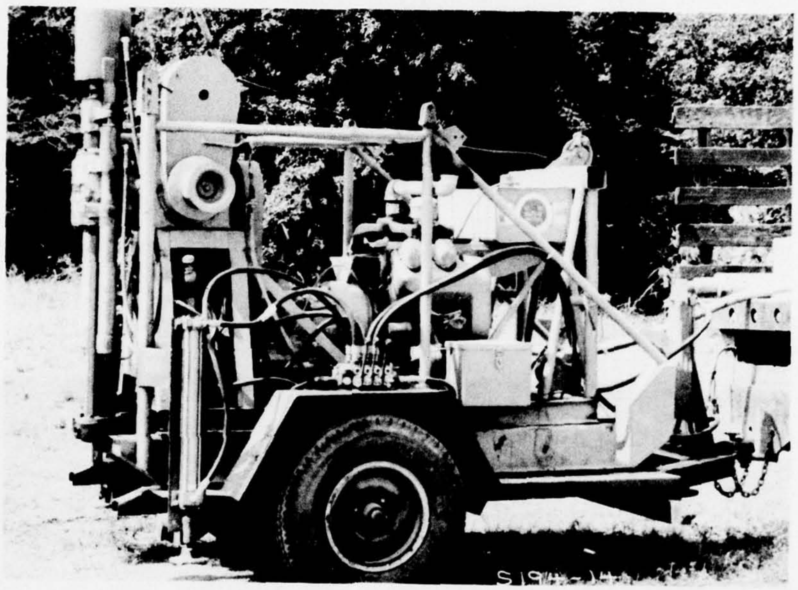

Photo 23. Trailer-mounted drill rig used for SAT

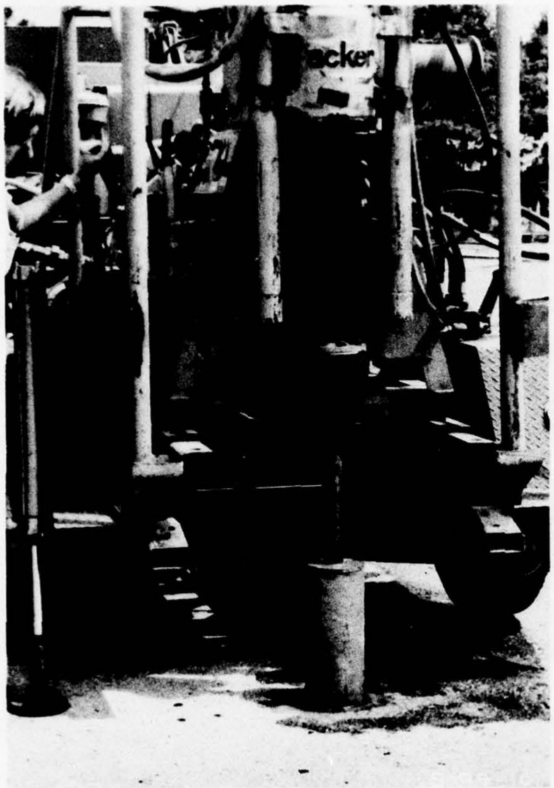

Photo 24. SAT drill rig coring asphalt

Photo 25. SAT auger for base and subbase

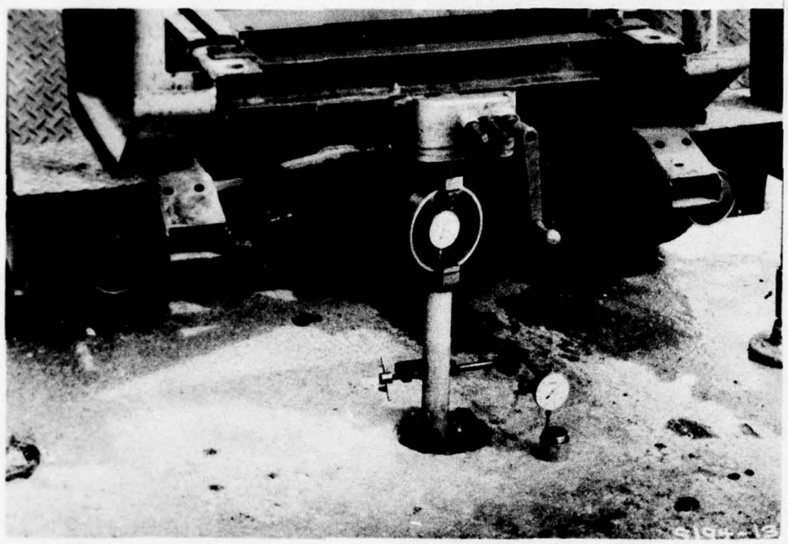

Photo 26. CBR test setup for SAT

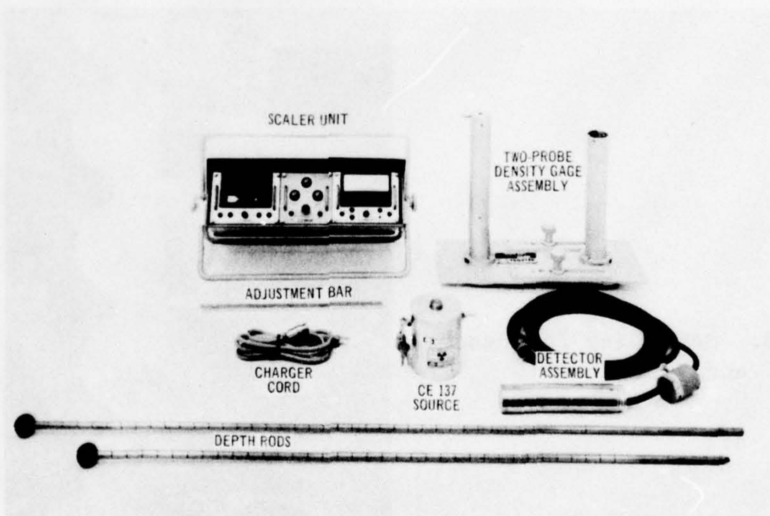

Photo 27. Components of WES nuclear density device

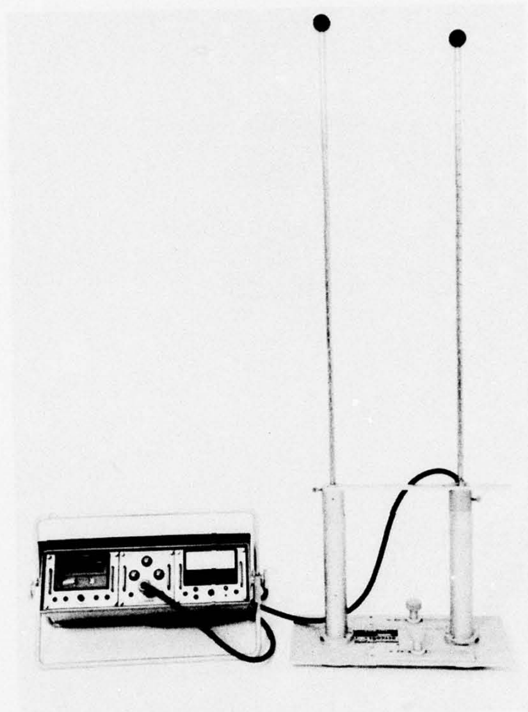

Photo 28. Assembled WES nuclear density device

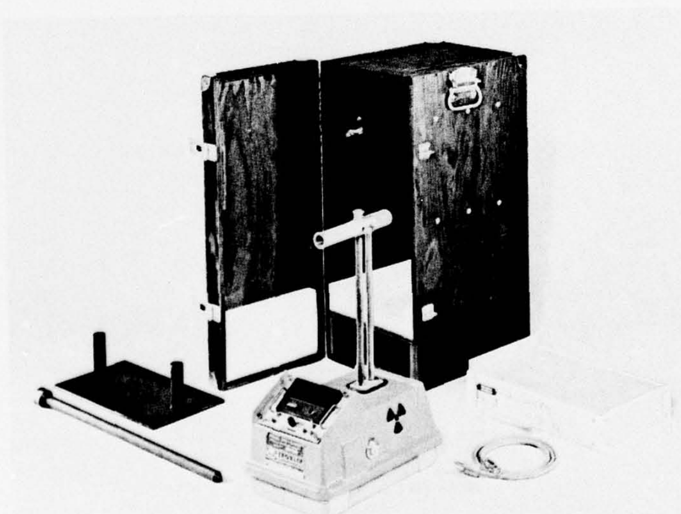

Photo 29. Components of Troxler nuclear density device

APPENDIX A: DETERIORATION ANALYSIS MODULE

General

1. The Deterioration Analysis Module is presented as the sixth module of the VRCAMS discussed earlier in this report. Barber and Murphy[7*] give a complete description of the VRCAMS along with the computer programs. The VRCAMS consists basically of two distinct computer programs referred to as SPEED and ROAD I. The Deterioration Analysis Module (DM) is the fourth overlay (OVRL 4) of the ROAD I program and can be utilized in conjunction with ROAD I or as a separate program. The entire analysis system (VRCAMS), including the DM (OVRL 4), is written in time-sharing FORTRAN IV language for the WES GE 600 computer system. Programs SPEED, ROAD I, and OVRL 4 are designed for remote access and execution from a teletype terminal. All input and output can be sent and received remotely through the terminal.

Deterioration Analysis Module

2. The DM is a computational tool designed to show the effects of road deterioration on the capability of that road to accommodate traffic. The DM utilizes the vehicle speed and its change as a function of traffic operations to show a decrease in traffic volume at capacity and at a maximum service level as a function of traffic operations and time, respectively.

Deterioration relationship

3. The purpose of this report has been to show the results and analyses of tests instrumented in the deterioration relationships. The tests indicated that deterioration relationships can be developed despite inadequate time during this study to attain the necessary volume of data. The specific relationships to be developed are expected to be in terms of roughness increase as a function of road use and other

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* Raised numbers refer to similarly numbered items in the References at the end of the main text.

governing conditions. Upon development of such relationships in terms suitable for use in the DM, the roughness parameter can be successfully related to vehicle speed. Since vehicle speed is the primary input parameter of the VRCAMS and is the parameter upon which computations are based, a relationship that shows speed change as a function of operations will constitute a satisfactory deterioration relationship or family of relationships.

Tentative relationship

4. In view of the fact that data reflected in this report did not provide for comprehensive development of deterioration relationships, and since further development of the relationships appears feasible in the near future, a hypothetical relationship is utilized herein that will be replaced by actual relationships. The hypothetical deterioration relationship used in development of the DM is a linear relationship that expresses the deterioration in vehicle speed, which is a result of roughness increase, as a function of vehicle operations. According to Corps of Engineers criteria, the road has reached or is approaching failure when this linear relationship indicates that the maximum running speed has deteriorated to a value equivalent to the speed at capacity. The relationship is shown in Figure A1. The S_{RUN} value (running speed) as well as a correlating S_{OPT} (optimum speed) is shown. This hypothetical relationship is assumed in contrast to the philosophy that a road maintains constant capability up to the time of failure.

Effects of hypothetical relationship

5. The primary observation made in the use of a hypothetical, linear deterioration relationship has been that more accurate output is obtained where the road capability is determined after considerable use and time have transpired. This observation suggests that if a hypothetical relationship developed in a manner that simulates real-life circumstances can improve determination of vehicle/road compatibility, then any deterioration relationship developed from appropriate data will significantly advance the capability to portray the value of a road. It then follows that quantitative decisions can be made as to

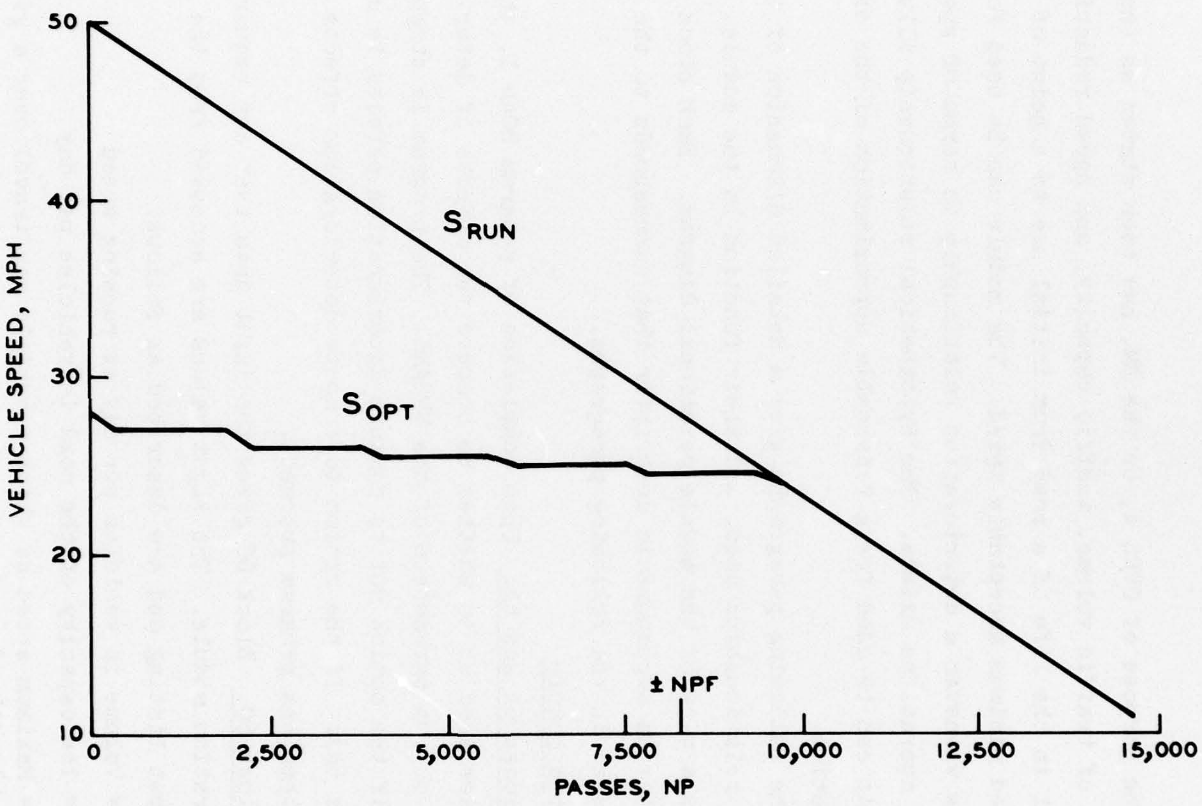

Figure A1. Hypothetical relationship of vehicle speed versus vehicle operations

maintenance and repair needs. This constitutes the basis of quantitative, effective, life-cycle management.

OVRL 4

6. The purpose of OVRL 4, or the DM, has been stated as the computation of traffic volume, traffic capacity, and speed reduction at any point in the life of a road from initial use to a point of predetermined minimum acceptable speed. The module can be used for computations whenever a deterioration relationship in terms of speed and traffic operations exists. The hypothetical relationship illustrated herein can be used for a reasonable approximation of the effects of deterioration.

7. The following paragraphs give a detailed discussion of the module, the relationships used, and their function in the module. Figure A2 gives a view of the module relational diagram. Each block in the figure has an alphanumeric descriptor that corresponds to the descriptions used in the following paragraphs.

Details of the module

8. Blocks 6A and 6B. Upon completion of program ROAD I, the option is exercised as to whether to compute the effects of deterioration on the output parameters of the VRCAMS. The program is stopped (Block 6B) if the option not to compute deterioration effects is exercised (Block 6A). If the option to compute deterioration effects is exercised, then the program proceeds.

9. Block 6C. Block 6C gives the input data that are required for the deterioration module. The input values are accessed from the ROAD I program output listing and are described as follows:

V^*_N = Volume in vehicles per day at running speed

C^*_N = The capacity of the road in vehicles per day

$\bar{S}_{RUN}$ = Maximum speed at which a vehicle can travel over a given length of road

S_{OPT} = Speed at which capacity is achieved

D_{OPT} = Optimum density, vehicles per mile

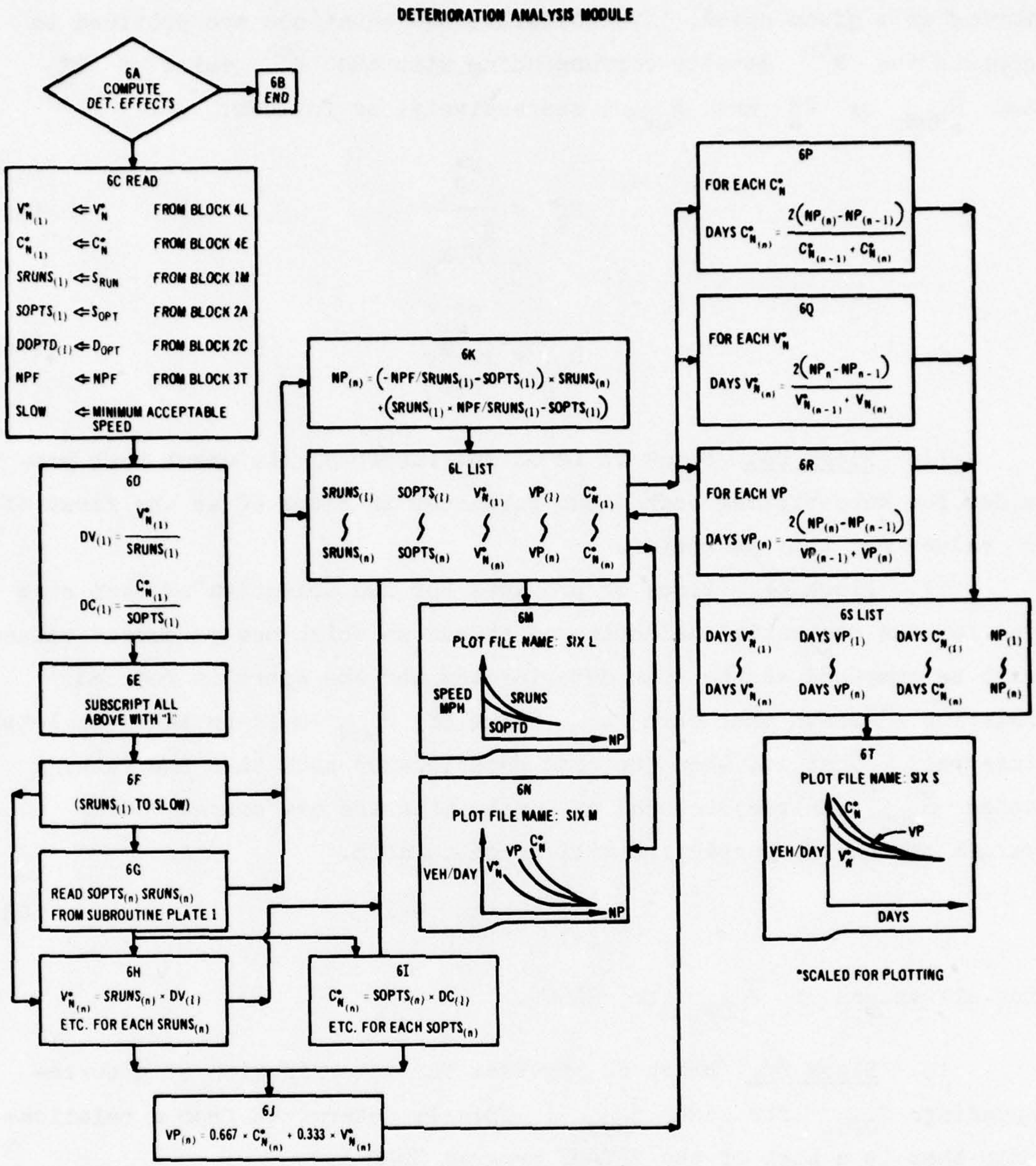

Figure A2. Deterioration analysis module of VRCAMS

NPF = Number of vehicle passes to failure

SLOW = Minimum speed at which vehicles are permitted to operate (e.g., a minimum value of $\overline{S}_{RUN}$)

10. Block 6D. Block 6D provides for the computation of any density in vehicles per mile that corresponds to a volume of vehicles

moving at a given speed. Specifically, two equations are provided to compute the N^{th} density corresponding with the N^{th} value of V^*_N and $\overline{S}_{RUN}$ or C^*_N and S_{OPT}, respectively, as follows:

$$D_{V_n} = \frac{V^*_{n_n}}{\overline{S}_{RUN_n}} \tag{A1}$$

$$D_{C_n} = \frac{C^*_{n_n}}{S_{OPT_n}} \tag{A2}$$

11. Block 6E. Block 6E is an instructional statement that provides for subscripting each input parameter in Block 6C as the first of n values for that parameter.

12. Block 6F. Block 6F provides for the selection of step size and for the sequential selection of speeds at which new parameter values will be computed as the road deteriorates and the speed is reduced. Equation A3 shows that each n^{th} value of $\overline{S}_{RUN}$ will be taken at 1-mph intervals. That is, when the road deteriorates such that the running speed $\overline{S}_{RUN}$ has been reduced by 1 mph, then the new corresponding values of the key parameters will be calculated.

$$\overline{S}_{RUN_{n+1}} = S_{RUN_n} - 1 \tag{A3}$$

for all values of $\overline{S}_{RUN_1}$ to SLOW .

13. Block 6G. Block 6G provides for determination of a corresponding S_{OPT_n} for each $\overline{S}_{RUN_n}$. This is determined from a relationship that is a part of the VRCAMS program ROAD I.[7]

14. Block 6H. This block shows the relationship for computation of a new corresponding traffic volume V^*_n for each n^{th} value of $\overline{S}_{RUN}$ and its corresponding D_V .

$$V^*_{N_n} = \overline{S}_{RUN_n} \times D_{V_n} \tag{A4}$$

for each S_{RUN_n} and each D_{V_n} .

15. Block 6I. Here the relationship is given for the computation of each new value of the capacity of the road $C^*_{N_n}$ that corresponds to each n^{th} value of S_{OPT_n} and D_{C_n}.

$$C^*_{N_n} = S_{OPT_n} \times D_{C_n} \tag{A5}$$

16. Block 6J. Block 6J gives a relationship for computation of a probabilistic traffic volume less than capacity (V_P) that is to be utilized in cases where projected road use is less than capacity but a higher value than that achieved at the maximum attainable speed. This value is necessary for use in planning purposes since the capacity situation will not occur at all times, and the user will require this probabilistic value for planning purposes. The equation for the probable volume on a road where traffic use has not been determined is as follows:

$$V_{P_n} = 0.667C^*_{N_n} + 0.333V^*_{N_n} \tag{A6}$$

where the constants shown are weighting functions that provide for an estimate nearer to capacity.

17. Block 6K. Block 6K provides the key relationship for this module. It is in this block that the current hypothetical deterioration relationship is expressed and where future validated relationships will be shown. Although the relationship shown represents a linear function, it is expected that regression techniques will be utilized to develop relationships that realistically represent actual data. Based upon the assumption of a linear deterioration in the speed value as a function of vehicle operations, the deterioration relationship is expressed as follows:

$$NP_n = \left[-NPF/\left(\overline{S}_{RUN_1} - S_{OPT_1}\right)\right]\left(\overline{S}_{RUN_n}\right)$$
$$+ \left(\overline{S}_{RUN_1} \times NPF\right)/\left(\overline{S}_{RUN_1} - S_{OPT_1}\right) \tag{A7}$$

where

NP_n = the number of vehicle passes that have transpired at the time the road has deteriorated to the n^{th} value of $\overline{S}_{RUN}$.

18. Block 6L. This block accomplishes the listing of the parameters computed in the previously described relationships. The values listed are the respective values corresponding to each n^{th} running speed that was selected. They are, respectively, $\overline{S}_{RUN}$, S_{OPT} , V_N^* , VP , C_N^* , and NP .

19. Block 6M. If desired, the listing for vehicle speed in terms of $\overline{S}_{RUN}$ or S_{OPT} can be plotted as a function of vehicle passes over a road. The plot is represented in Block 6M of Figure A2. Figure A2 gives the result of the plot of the values used in the example problem that will be discussed in following paragraphs.

20. Block 6N. This block provides for the plotting of the various volumes (e.g., C_N^* , VP , and V_N^*) as a function of vehicle passes. While Block 6N of Figure A2 gives an illustration, Figure A3 gives the results in graphic form of the values obtained from the example problem. Plotting tabular data in this form can give the road user a clearer understanding of the attrition in the traffic volumes as a function of traffic passes.

21. Blocks 6P, 6Q, and 6R. The deterioration module to this point has provided for the computation of traffic volume and its change as a function of vehicle passes accumulated on the road in question. Certain needs of potential program users, specifically in the area of military planning, could dictate the need to know the extent of road deterioration and volume reduction in terms of time. The relationships, plotted as shown in Figure A3, indicate that through the deterioration rate, traffic volume is a function of the number of passes. Since traffic volume itself is a rate in terms of vehicles per day, it is possible to determine the days required to accumulate the various numbers of passes (NP) over the road. It is then possible to develop a set of equations that reflect the traffic volumes C_N^* , VP , and V_N^* as a function of time. The following equations are expressions for this purpose.

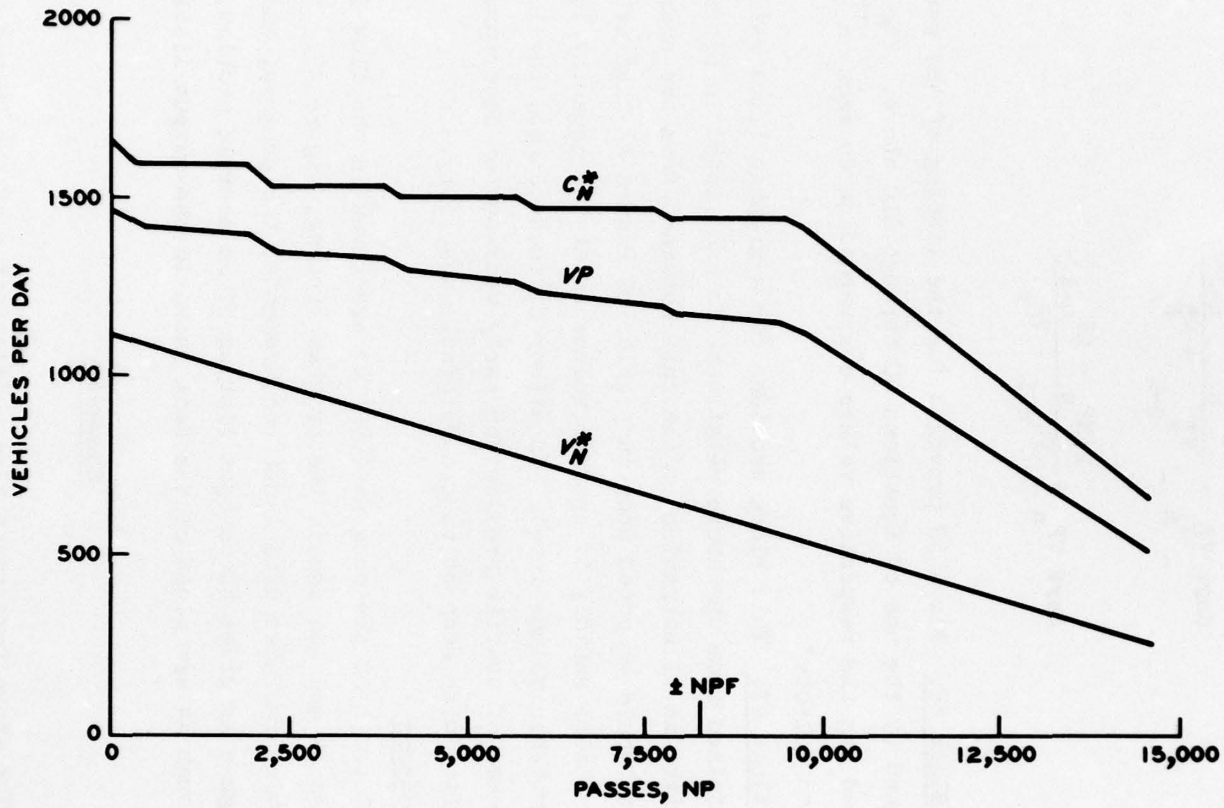

Figure A3. Traffic volume versus cumulative vehicle operations

$$\text{days } C^*_{N_n} = \frac{2(NP_n - NP_{n-1})}{C^*_{N_{n-1}} + C^*_{N_n}} \qquad (A8)$$

$$\text{days } V^*_{N_n} = \frac{2(NP_n - NP_{n-1})}{V^*_{N_{n-1}} + V^*_{N_n}} \qquad (A9)$$

$$\text{days } VP_n = \frac{2(NP_n - NP_{n-1})}{VP_{n-1} + VP_n} \qquad (A10)$$

22. Block 6S. Block 6S provides for the listing of the parameters computed by the use of Equations A8 through A10 above. The values listed are the respective values corresponding to each n^{th} running speed selected.

23. Block 6T. This block provides for a graphic illustration of the data obtained from the above relationships and listed in Block 6S. Figure A4 gives an illustration of the data obtained from the example problem. It should be noted upon inspection of Figure A4 that deterioration occurs more rapidly if traffic volume is at the capacity level or at the probable volume level. In either of these cases, the large initial volumes of traffic provide for early wear-out or deterioration of the facility with respect to its original capability.

Computer programs

24. Details of the program (OVRL 4) are given in the flow diagram, Figures A5 and A6, and in the program listing, Figure A7. The program listing includes data input requirements, the program, and output. Figure A8 gives the output listing of an example problem; Figures A2 through A4 are plots of the data shown in the output listing.

Summary

25. The above paragraphs give a description of the DM and its utilization of deterioration relationships. The hypothetical deterioration relationship utilized illustrates the validity of the deterioration

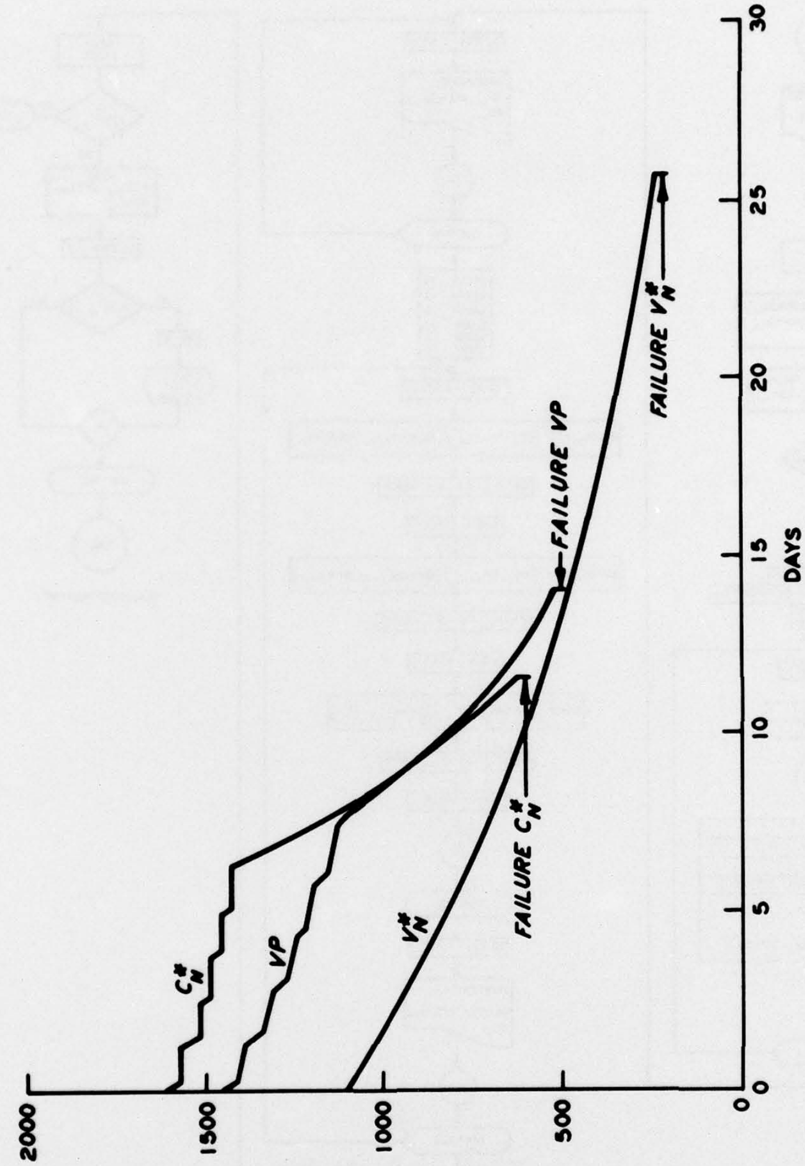

Figure A4. Traffic volume versus time

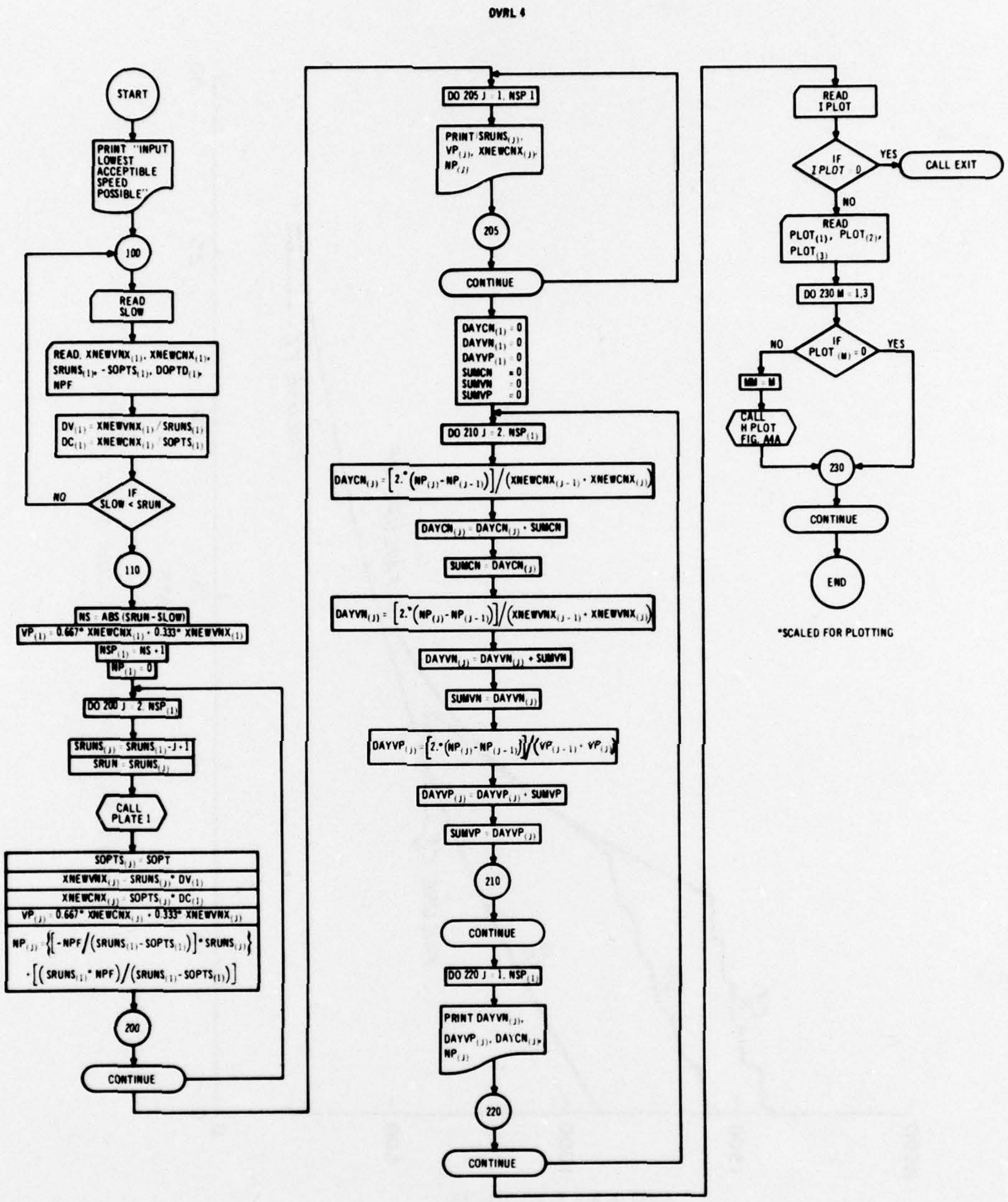

Figure A5. Flow diagram of OVRL 4 program

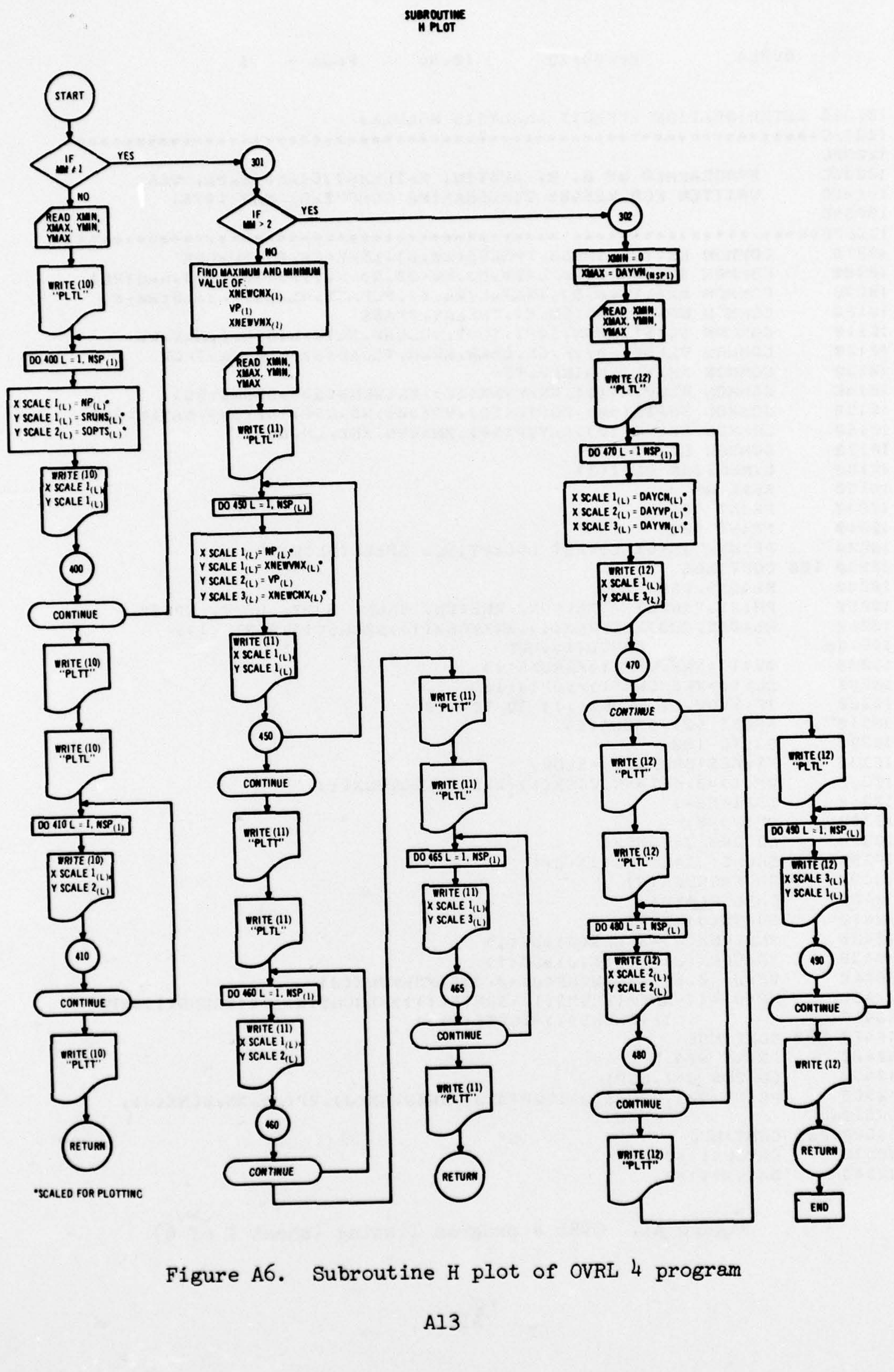

Figure A6. Subroutine H plot of OVRL 4 program

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C DETERIORATION EFFECTS ANALYSIS MODULE.
C*****************************************************************
C
C      PROGRAMMED BY H. R. AUSTIN, MATHEMATICIAN, S&PL, WES.
C      WRITTEN FOR WES600 TIMESHARING COMPUTER, MAY 1975.
C
C*****************************************************************
       COMMON NRTYPE,SPASS,TPRESS(20,8),ESWL(20,8),SUBCBR
       COMMON SURCBR,COVAXG(20,8),NW(20,8),NVT,PVTYPE(20),NAG(20)
       COMMON AXELL(20,8),ITAXEL(20,8),PCFACT,NLANE,PASSES(20,8)
       COMMON NPF,WSPAC(20,8),THSLAY,PPASS
       COMMON SDIST,SRUN,SOPT,TOPT,VOLCAP,KEYW,DISTO,LANEW,WC
       COMMON VLENG(20),F,CN,DBAR,NVEH,TLOAD(20),DR,VN,TFDV
       COMMON XM,XLI,MAINAV,TC
       COMMON SLOW,DV(1),XNEWVNX(50),XNEWCNX(50),SRUNS(50)
       COMMON SOPTS(50),DOPTD(50),VP(50),NS,NSP1,NP(50),DAYCN(50)
       COMMON DAYVN(50),DAYVP(50),XNEWVN,XNEWCN,DOPT
       COMMON DC(1)
       DIMENSION PLOT(3)
       REAL NP
       PRINT 906
       PRINT 908
       PRINT,"INPUT LOWEST ACCEPTIBLE SPEED(SLOW)?"
   100 CONTINUE
       READ(5,900)SLOW
       PRINT,"INPUT - XNEWVN, XNEWCN, SRUN, SOPT, DOPT, NPF?"
       READ(5,900)XNEWVNX(1),XNEWCNX(1),SRUNS(1),SOPTS(1),
&                DOPTD(1),NPF
       DV(1)=XNEWVNX(1)/SRUNS(1)
       DC(1)=XNEWCNX(1)/SOPTS(1)
       IF(SLOW.LT.SRUNS(1)) GO TO 110
       PRINT 901,SRUNS(1)
       GO TO 100
   110 NS=ABS(SRUNS(1)-SLOW)
       VP(1)=0.667*XNEWCNX(1)+0.333*XNEWVNX(1)
       NSP1=NS+1
       NP(1)=0.
       DO 200 J=2,NSP1
       SRUNS(J)=SRUNS(1)-J+1
       SRUN=SRUNS(J)
       CALL PLATE1
       SOPTS(J)=SOPT
       XNEWVNX(J)=SRUNS(J)*DV(1)
       XNEWCNX(J)=SOPTS(J)*DC(1)
       VP(J)=0.667*XNEWCNX(J)+0.333*XNEWVNX(J)
       NP(J)=((-NPF/(SRUNS(1)-SOPTS(1)))*SRUNS(J))+((SRUNS(1)*NPF
&      )/(SRUNS(1)-SOPTS(1)))
   200 CONTINUE
       PRINT 904
       DO 205 J=1,NSP1
       PRINT 905,SRUNS(J),SOPTS(J),XNEWVNX(J),VP(J),XNEWCNX(J),
&               NP(J)
   205 CONTINUE
       DAYCN(1)=0.
       DAYVN(1)=0.
```

Figure A7. OVRL 4 program listing (sheet 1 of 6)

```
     DAYVP(1)=0.
     SUMCN=0.
     SUMVN=0.
     SUMVP=0.
     DO 210 J=2,NSP1
     DAYCN(J)=(2.*(NP(J)-NP(J-1)))/(XNEWCNX(J-1)+XNEWCNX(J))
     DAYCN(J)=DAYCN(J)+SUMCN
     SUMCN=DAYCN(J)
     DAYVN(J)=(2.*(NP(J)-NP(J-1)))/(XNEWVNX(J-1)+XNEWVNX(J))
     DAYVN(J)=DAYVN(J)+SUMVN
     SUMVN=DAYVN(J)
     DAYVP(J)=(2.*(NP(J)-NP(J-1)))/(VP(J-1)+VP(J))
     DAYVP(J)=DAYVP(J)+SUMVP
     SUMVP=DAYVP(J)
210  CONTINUE
     PRINT 906
     PRINT 902
     DO 220 J=1,NSP1
     PRINT 903,DAYVN(J),DAYVP(J),DAYCN(J),NP(J)
220  CONTINUE
     PRINT 906
*
*
*
     PRINT,"THE PROGRAM IS READY TO PLOT. IF PLOTTING IS DESIRED"
     PRINT,"TYPE A 1, IF NO PLOTTING IS DESIRED TYPE A 0."
     READ(5,900)IPLOT
     IF(IPLOT.EQ.0)CALL EXIT
     PRINT,"SELECT THE DESIRED PLOTS. IF A PLOT IS NEEDED,"
     PRINT,"TYPE A 1, IF NOT, TYPE A 0. YOUR CHOICES SHOULD FOLLOW"
     PRINT,"THIS ORDER 6L, 6M, 6S."
     READ(5,900)PLOT(1),PLOT(2),PLOT(3)
     DO 230 M=1,3
     IF(PLOT(M).EQ.0)GO TO 230
     MM=M
     CALL HPLOT(MM)
230  CONTINUE
900  FORMAT(V)
901  FORMAT("INPUT NEW SLOW -- SLOW MUST BE < ",F8.0//)
902  FORMAT(5X,8HDAYS-V*N,7X,7HDAYS-VP,8X,8HDAYS-C*N,10X,2HNP)
903  FORMAT(1X,4F15.0)
904  FORMAT(//"  SRUN  SOPT       V*N            VP           C*N
&            NP")
905  FORMAT(2F6.0,4F12.0)
906  FORMAT(///)
908  FORMAT(22X,28HDETERIORATION EFFECTS MODULE ///)
     STOP
     END
     SUBROUTINE HPLOT(MM)
C
C PLOTS DATA ON HEWLETT PACKARD 7200A GRAPHIC PLOTTER.
C
     COMMON NRTYPE,SPASS,TPRESS(20,8),ESWL(20,8),SUBCBR
     COMMON SURCBR,COVAXG(20,8),NW(20,8),NVT,PVTYPE(20),NAG(20)
     COMMON AXELL(20,8),ITAXEL(20,8),PCFACT,NLANE,PASSES(20,8)
```

Figure A7 (sheet 2 of 6)

```
      COMMON NPF,WSPAC(20,8),THSLAY,PPASS
      COMMON SDIST,SRUN,SOPT,TOPT,VOLCAP,KEYW,DISTO,LANEW,WC
      COMMON VLENG(20),F,CN,DBAR,NVEH,TLOAD(20),DR,VN,TFDV
      COMMON XM,XLI,MAINAV,TC
      COMMON SLOW,DV(1),XNEWVNX(50),XNEWCNX(50),SRUNS(50)
      COMMON SOPTS(50),DOPTD(50),VP(50),NS,NSP1,NP(50),DAYCN(50)
      COMMON DAYVN(50),LAYVP(50),XNEWVN,XNEWCN,DOPT
      COMMON DC(1)
      DIMENSION XSCALE1(50),YSCALE1(50),YSCALE2(50),YSCALE3(50)
      DIMENSION XSCALE2(50),XSCALE3(50)
      DIMENSION SH(3),SV(3),PH(3),PV(3),GH(3),GV(3)
      REAL NP
      INTEGER XSCALE1,YSCALE1,YSCALE2,YSCALE3
      INTEGER XSCALE2,XSCALE3
      DATA SH/6.,6.,6./,SV/4.,4.,4./
      DATA PH/1.,1.,9./,PV/1.,6.,6./
      DATA GH/15.,15.,15./,GV/10.,10.,10./
      IF(MM.NE.1) GO TO 301
      PRINT,NP(1),NP(NSP1),SLOW,SRUNS(1)
      PRINT,"INPUT - XMIN, XMAX, YMIN, YMAX?"
      READ(5,900)XMIN, XMAX, YMIN, YMAX
      CALL ATTACH(10,"/SIXL;",3,0,,)
      WRITE(10,902)
C SCALE DATA FOR 6L.
      DO 400 L=1,NSP1
      XSCALE1(L)=((NP(L)-XMIN)/(XMAX-XMIN))*9999.*(SH(MM)/GH(MM))
&                 +9999.*(PH(MM)/GH(MM))
      YSCALE1(L)=((SRUNS(L)-YMIN)/(YMAX-YMIN))*9999.*(SV(MM)/
&                 GV(MM))+9999.*(PV(MM)/GV(MM))
      YSCALE2(L)=((SOPTS(L)-YMIN)/(YMAX-YMIN))*9999.*(SV(MM)/
&                 GV(MM))+9999.*(PV(MM)/GV(MM))
      WRITE(10,901)XSCALE1(L),YSCALE1(L)
  400 CONTINUE
      WRITE(10,903)
      WRITE(10,902)
      DO 410 L=1,NSP1
      WRITE(10,901)XSCALE1(L),YSCALE2(L)
  410 CONTINUE
      WRITE(10,903)
      CALL DETACH(10,,)
      RETURN
  301 IF(MM.GT.2)GO TO 302
      YMIN=55E+10
      YMAX=-55E-10
      DO 420 I=1,NSP1
      YMIN=AMIN1(YMIN,XNEWCNX(I))
      YMAX=AMAX1(YMAX,XNEWCNX(I))
  420 CONTINUE
      DO 430 I=1,NSP1
      YMIN=AMIN1(YMIN,VP(I))
      YMAX=AMAX1(YMAX,VP(I))
  430 CONTINUE
      DO 440 I=1,NSP1
      YMIN=AMIN1(YMIN,XNEWVNX(I))
      YMAX=AMAX1(YMAX,XNEWVNX(I))
```

Figure A7 (sheet 3 of 6)

```
 440 CONTINUE
     PRINT,NP(1),NP(NSP1),YMIN,YMAX
     PRINT,"INPUT - XMIN, XMAX, YMIN, YMAX?"
     READ(5,900)XMIN,XMAX,YMIN,YMAX
     CALL ATTACH(11,"/SIXM;",3,0,,)
     WRITE(11,902)
C SCALE DATA FOR 6M.
     DO 450 L=1,NSP1
     XSCALE1(L)=((NP(L)-XMIN)/(XMAX-XMIN))*9999.*SH(MM)/GH(MM)+
&               9999.*(PH(MM)/GH(MM))
     YSCALE1(L)=((XNEWVNX(L)-YMIN)/(YMAX-YMIN))*9999.*SV(MM)/GV(MM)
&               9999.*(PV(MM)/GV(MM))
     YSCALE2(L)=((VP(L)-YMIN)/(YMAX-YMIN))*9999.*SV(MM)/GV(MM)+
&               9999.*(PV(MM)/GV(MM))
     YSCALE3(L)=((XNEWCNX(L)-YMIN)/(YMAX-YMIN))*9999.*SV(MM)/GV(MM)
&               9999.*(PV(MM)/GV(MM))
     WRITE(11,901)XSCALE1(L),YSCALE1(L)
 450 CONTINUE
     WRITE(11,903)
     WRITE(11,902)
     DO 460 L=1,NSP1
     WRITE(11,901)XSCALE1(L),YSCALE2(L)
 460 CONTINUE
     WRITE(11,903)
     WRITE(11,902)
     DO 465 L=1,NSP1
     WRITE(11,901)XSCALE1(L),YSCALE3(L)
 465 CONTINUE
     WRITE(11,903)
     CALL DETACH(11,,)
     RETURN
 302 CONTINUE
     XMIN=0.
     XMAX=DAYVN(NSP1)
     PRINT,XMIN,DAYVN(NSP1),YMIN,YMAX
     PRINT,"XMIN, XMAX, YMIN, YMAX"
     READ(5,900)XMIN,XMAX,YMIN,YMAX
     CALL ATTACH(12,"/SIXS;",3,0,,)
     WRITE(12,902)
C SCALE DATA FOR 6S.
     DO 470 L=1,NSP1
     XSCALE1(L)=((DAYCN(L)-XMIN)/(XMAX-XMIN))*9999.*SH(MM)/
&                 GH(MM)+9999.*(PH(MM)/GH(MM))
     XSCALE2(L)=((DAYVP(L)-XMIN)/(XMAX-XMIN))*9999.*SH(MM)/GH(MM)+
&               9999.*(PH(MM)/GH(MM))
     XSCALE3(L)=((DAYVN(L)-XMIN)/(XMAX-XMIN))*9999.*SH(MM)/GH(MM)+
&               9999.*(PH(MM)/GH(MM))
     WRITE(12,901)XSCALE1(L),YSCALE3(L)
 470 CONTINUE
     WRITE(12,903)
     WRITE(12,902)
     DO 480 L=1,NSP1
     WRITE(12,901)XSCALE2(L),YSCALE2(L)
 480 CONTINUE
     WRITE(12,903)
```

Figure A7 (sheet 4 of 6)

```
      WRITE(12,902)
      DO 490 L=1,NSP1
      WRITE(12,901)XSCALE3(L),YSCALE1(L)
  490 CONTINUE
      WRITE(12,903)
      CALL DETACH(12,,)
      RETURN
  900 FORMAT(V)
  901 FORMAT(I4,1X,I4)
  902 FORMAT("PLTL")
  903 FORMAT("PLTT")
      END
      SUBROUTINE PLATE1
C THIS SUBROUTINE FINDS SOPT(OPTIMUM SPEED(MPH)),
C WHEN GIVEN SRUN(RUNNING SPEED(MPH)),
      COMMON NRTYPE,SPASS,TPRESS(20,8),ESWL(20,8),SUBCBR
      COMMON SURCBR,COVAXG(20,8),NW(20,8),NVT,PVTYPE(20),NAG(20)
      COMMON AXELL(20,8),ITAXEL(20,8),PCFACT,NLANE,PASSES(20,8)
      COMMON NPF,WSPAC(20,8),THSLAY,PPASS
      COMMON SDIST,SRUN,SOPT,TOPT,VOLCAP,KEYW,DISTO,LANEW,WC
      COMMON VLENG(20),F,CN,DBAR,NVEH,TLOAD(20),DR,VN,TFDV
      COMMON XM,XLI,MAINAV,TC
      COMMON SLOW,DV(1),XNEWVNX(50),XNEWCNX(50),SRUNS(50)
      COMMON SOPTS(50),DOPTD(50),VP(50),NS,NSP1,NP(50),DAYCN(50)
      COMMON DAYVN(50),DAYVP(50),XNEWVN,XNEWCN,DOPT
      COMMON DC(1)
      INTEGER SDIST
      IF(SRUN.GT.24.)GO TO 20
      SOPT=SRUN
      RETURN
   20 IF(SRUN.GT.29.)GO TO 22
      SOPT=24.5
      RETURN
   22 IF(SRUN.GT.34.)GO TO 24
      SOPT=25.
      RETURN
   24 IF(SRUN.GT.39.)GO TO 26
      SOPT=25.5
      RETURN
   26 IF(SRUN.GT.44.)GO TO 28
      SOPT=26.
      RETURN
   28 IF(SRUN.GT.49.)GO TO 30
      SOPT=27.
      RETURN
   30 IF(SRUN.GT.59.)GO TO 32
      SOPT=28.
      RETURN
   32 IF(SRUN.GT.69.)GO TO 34
      SOPT=30.
      RETURN
   34 IF(SRUN.GT.79.)GO TO 36
      SOPT=32.5
      RETURN
C ANY SRUN > 79(MPH) ,THEN SOPT IS SET = 35(MPH).
```

Figure A7 (sheet 5 of 6)

```
          OVRL4          06/03/75        10.46      PAGE -   6

   36 SOPT=35.
      RETURN
      END
```

Figure A7 (sheet 6 of 6)

DETERIORATION EFFECTS MODULE

```
INPUT LOWEST ACCEPTIBLE SPEED(SLOW)?
=11.
INPUT - XNEWVN, XNEWCN, SRUN, SOPT, DOPT, NPF?
=1098. 1632. 50. 28. 39.48 8218
```

SRUN	SOPT	V*N	VP	C*N	NP
50.	28.	1098.	1454.	1632.	0.
49.	27.	1076.	1408.	1574.	374.
48.	27.	1054.	1401.	1574.	747.
47.	27.	1032.	1393.	1574.	1121.
46.	27.	1010.	1386.	1574.	1494.
45.	27.	988.	1379.	1574.	1868.
44.	26.	966.	1333.	1515.	2241.
43.	26.	944.	1325.	1515.	2615.
42.	26.	922.	1318.	1515.	2988.
41.	26.	900.	1311.	1515.	3362.
40.	26.	878.	1303.	1515.	3735.
39.	26.	856.	1277.	1486.	4109.
38.	26.	834.	1269.	1486.	4483.
37.	26.	813.	1262.	1486.	4856.
36.	26.	791.	1255.	1486.	5230.
35.	26.	769.	1247.	1486.	5603.
34.	25.	747.	1221.	1457.	5977.
33.	25.	725.	1213.	1457.	6350.
32.	25.	703.	1206.	1457.	6724.
31.	25.	681.	1199.	1457.	7097.
30.	25.	659.	1191.	1457.	7471.
29.	25.	637.	1165.	1428.	7844.
28.	25.	615.	1157.	1428.	8218.
27.	25.	593.	1150.	1428.	8592.
26.	25.	571.	1143.	1428.	8965.
25.	25.	549.	1135.	1428.	9339.
24.	24.	527.	1109.	1399.	9712.
23.	23.	505.	1062.	1341.	10086.
22.	22.	483.	1016.	1282.	10459.
21.	21.	461.	970.	1224.	10833.
20.	20.	439.	924.	1166.	11206.
19.	19.	417.	878.	1107.	11580.
18.	18.	395.	831.	1049.	11953.
17.	17.	373.	785.	991.	12327.
16.	16.	351.	739.	933.	12701.
15.	15.	329.	693.	874.	13074.
14.	14.	307.	647.	816.	13448.
13.	13.	285.	600.	758.	13821.
12.	12.	264.	554.	699.	14195.
11.	11.	242.	508.	641.	14568.

Figure A8. OVRL 4 program output listing (sheet 1 of 2)

DAYS-V*N	DAYS-VP	DAYS-C*N	NP
0.	0	0.	0.
0.	0	0.	374.
1.	1	0.	747.
1.	1.	1.	1121.
1.	1.	1.	1494.
2.	1.	1.	1868.
2.	2.	1.	2241.
3.	2.	2.	2615.
3.	2.	2.	2988.
3.	2.	2.	3362.
4.	3.	2.	3735.
4.	3.	3.	4109.
5.	3.	3.	4483.
5.	4.	3.	4856.
6.	4.	3.	5230.
6.	4.	4.	5603.
7.	5.	4.	5977.
7.	5.	4.	6350.
8.	5.	4.	6724.
8.	5.	5.	7097.
9.	6.	5.	7471.
9.	6.	5.	7844.
10.	6.	5.	8218.
10.	7.	6.	8592.
11.	7.	6.	8965.
12.	7.	6.	9339.
12.	8.	7.	9712.
13.	8.	7.	10086.
14.	8.	7.	10459.
15.	9.	7.	10833.
16.	9.	8.	11206.
16.	10.	8.	11580.
17.	10.	8.	11953.
18.	10.	9.	12327.
19.	11.	9.	12701.
20.	12.	10.	13074.
22.	12.	10.	13448.
23.	13.	10.	13821.
24.	13.	11.	14195.
26.	14.	12.	14568.

```
THE PROGRAM IS READY TO PLOT. IF PLOTTING IS DESIRED
TYPE A 1, IF NO PLOTTING IS DESIRED TYPE A 0.
=1
SELECT THE DESIRED PLOTS. IF A PLOT IS NEEDED,
TYPE A 1, IF NOT, TYPE A 0. YOUR CHOICES SHOULD FOLLOW
THIS ORDER 6L, 6M, 6S.
=1 1 1
  0.              0.14568273E 05  0.110000000E 02  0.500000000E 02
INPUT - XMIN, XMAX, YMIN, YMAX?
=0. 15000. 10. 50.
  0.              0.14568273E 05  0.241560000E 03  0.163200000E 04
INPUT - XMIN, XMAX, YMIN, YMAX?
=0. 15000. 0. 2000.
  0.              0.25750151E 02  0.                0.200000000E 04
XMIN, XMAX, YMIN, YMAX
=0. 30. 0. 2000.
```

Figure A8 (sheet 2 of 2)

concept by showing the decrease in the value of a road as a function of use and time. Though hypothetical, this relationship and the module discussed provide for close approximation of the attrition of volume and speed illustrated in Figures A2 through A4.

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Barber, Victor C
Pavement deterioration analysis for design and evaluation systems, by Victor C. Barber, Eugene C. Odom, [and] Robert W. Patrick. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1976.
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